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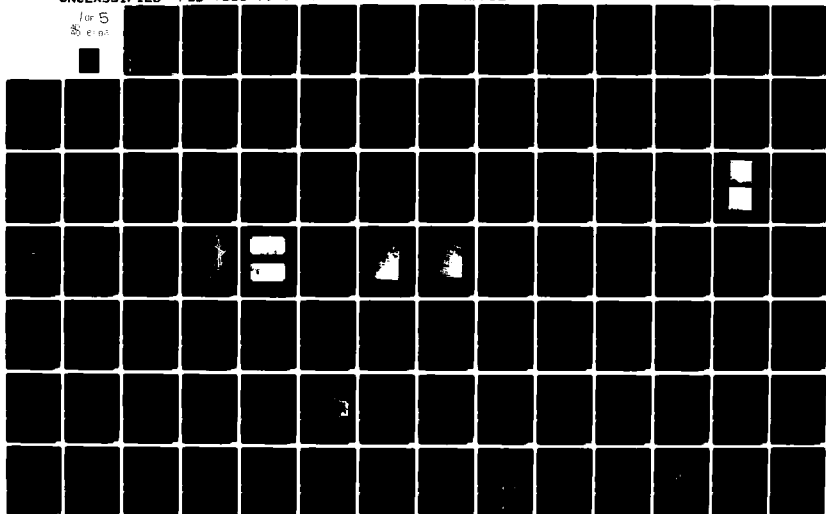
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CONTROL-DISPLAY INVESTIGATION OF COMPLEX TRAJECTORY FLIGHT USING THE MICROWAVE LANDING SYSTEM

**BENDIX CORPORATION
FLIGHT SYSTEMS DIVISION
TETERBORO, NEW JERSEY 07608**

DECEMBER 1979

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FINAL REPORT FOR PERIOD OCTOBER 1977 - MAY 1979

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**AIR FORCE FLIGHT DYNAMICS LABORATORY
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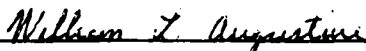
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21. ABSTRACT (Continue on reverse side if necessary and identify by block number) Report presents an analysis of overall control-display task for complex trajectory flight using MLS equipment. It explores the interrelationships of complex trajectory definition and geo- metry, approach plate design data entry, monitoring, displays, and controls. It recommends several electro-mechanical and electronic control-display configurations. It also recommends four candidate MLS equipment configurations with various levels of capability which are applicable to the USAF inventory.		

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20. ABSTRACT (Continued)

✓ MLS integration studies are presented for the C-130A/D, F-111A/E, A-7D, F-15A, and KC-10A.

FOREWORD

This document is the final report for the analysis phase of the Control-Display Investigation of Complex Trajectory Flight using the Microwave Landing System (MLS). The study was conducted by the Systems Engineering Department of The Bendix Corporation's Flight Systems Division under Contract F33615-77-C-2053 project number 404L0127 for the Crew Systems Development Branch, Flight Control Division, Air Force Flight Dynamics Laboratory (AFFDL), Air Force Systems Command at Wright-Patterson Air Force Base, Ohio. The Bendix Program Manager was Mr. R. Johnston; Messrs. W. Medlinski, H. Schmier, and R. Rover were major contributors to the report; and, Dr. Malcolm Ritchie of Ritchie Associates in Dayton, Ohio provided overall human factors consulting support. The AFFDL Program Manager was Mr. Terry J. Emerson; Mr. William Augustine was Project Engineer; and, Sqn. Ldr. Peter Clough and Mr. Eldon Bobbett provided technical assistance. Further technical and human factors assistance was provided by Mr. Peter Lovering of the Bunker Ramo Corporation. Overall program management and funding was provided by the USAF Electronic Systems Division, Tracal System Program Office under the direction of Seward Norris.

The effort described herein was initiated in October 1977.

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LIST OF ABBREVIATIONS

ADEU -Automatic Data Entry Unit	DOT - Department of Transportation
ADI - Attitude Director Indicator	DP - Descent Point
ALS - Advanced Landing System	DPA - Desired Path Angle
ALT - Altitude	DTK - Desired Track Angle
APPR -Approach	EADI -Electronic Attitude Director Indicator
ATC - Air Traffic Control	EHSI -Electronic Horizontal Situation Indicator
ATK - Along Track Distance to GPIP	ELEV -Elevation
AUX - Auxiliary	ENG - Engage
AZ - Azimuth	FAP - Final Approach Point
CADC -Central Air Data Computer	FDSU -Flight Data Storage Unit
CAT - Category	FIP - Final Intercept Point
CDI - Course Deviation Indicator	FPA - Flight Path Angle
CDU - Control Display Unit	FPI - Flight Profile Investigation
CRS - Course	FTP - Final Transition Point
CRT - Cathode Ray Tube	GOR - General Operation Requirement
CTOL -Conventional Takeoff and Landing	GPIP -Glide Path Intercept Point
CWS - Control Wheel Steering	GS - Glide Slope
cm - Centimeter	GSI - Glide Slope Indicator
DABS -Discrete Address Beacon System	GSP - Ground Speed
DAIS -Digital Avionics Instrumentation System	HDG - Heading
DIST -Distance	HSI - Horizontal Situation Indicator
DME - Distance Measuring Equipment	IAS - Indicated Airspeed
	ICAO -International Civil Aviation Organization
	IFR - Instrument Flight Rules

LIST OF ABBREVIATIONS - CONTINUED

ILS - Instrument Landing System	nm - Nautical Mile
ITP - Initial Transition Point	OTK - Outbound Track
ITK - Inbound Track	PAR - Precision Approach Radar
km - Kilometer	R - Right
L - Left	RAD - Radius
LCD - Liquid Crystal Display	RCVR -Receiver
LED - Light Emitting Diode	RF - Radio Frequency
LOC - Localizer	RNAV -Radio Navigation
MLS - Microwave Landing System	RTP - RNAV Transition Point
MLS-1-Direct ILS Replacement Configuration	RVR - Runway Visual Range
MLS-2-Selectable Elevation & Azimuth Configuration	RWP - Range-to-Waypoint
MLS-3-Selectable Intercept of Final Configuration	RWY - Runway
MLS-4-Complex Trajectory Configuration	SGMT- Segment
MMLS -Military MLS	STOL -Short Takeoff & Landing
MTBF -Mean Time Between Failure	TAC - TACAN (Navaid)
MTTR -Mean Time to Repair	TACAN-Tactical Air Navigation
m - Meter	TCV - Terminal Configured Vehicle
NAFEC-National Aviation Facilities Experimental Center	TERM -Terminal
NAV - Navigation	TRK - Track
NPA - Path Angle to Next Waypoint	TRSB -Time Reference Scanning Beam
	VFR - Visual Flight Rules
	VHF - Very High Frequency
	VNAV -Vertical Navigation
	VOR - VHF Onmidirectional Range
	VP - Vertical Flight Path
	VTK - Vertical Path Error
	WPT - Waypoint
	XMTR- Transmitter

LIST OF ABBREVIATIONS - CONTINUED

XTK - Cross Track Error 3-D - 3-Dimensional
2-D - 2-Dimensional

1.0 INTRODUCTION AND SUMMARY

1.1 Purpose

The purpose of the Control-and-Display Investigation of Complex Trajectory Flight using the Microwave Landing System (MLS) was to develop design criteria to enable all USAF aircraft to be fitted with the capability to fly MLS complex trajectories. The investigation was to include analysis, design definition and design validation phases. This is the final report for the analysis phase.

1.2 Background

The MLS technique adopted by the United States and by ICAO is the "Time Reference Scanning Beam (TRSB)". Phase III MLS ground and airborne equipment has been developed by several manufacturers. It provides three levels (see table below) of expanded volumetric coverage of precision guidance data which allows a suitably equipped aircraft fly a wide variety of curved path multi-segmented approach paths in the terminal area environment. The ability to fly these complex trajectories enables approaches to be designed that avoid hostile areas, obstructions and population centers.

MLS GROUND EQUIPMENT

<u>LEVEL</u>	<u>AZIMUTH</u>	<u>ELEVATION</u>	<u>RANGE</u>	<u>DME ACCURACY</u>
Small Community	$\pm 10^{\circ}$	1° to 15°	15nm	none
Basic Narrow	$\pm 40^{\circ}$	1° to 15°	20nm	100'
Basic Wide	$\pm 60^{\circ}$	1° to 15°	20nm	100'

Since 1971, a national program for the development of a universal civil/military MLS has been in progress. The program has been managed by the FAA and supported by the DOD and NASA. FAA efforts to date have been primarily directed toward resolving signal format and ground installation problems. The USAF and NASA have conducted programs to determine and resolve issues associated with aircraft dynamics, airborne systems and pilot acceptance of complex trajectory flight. NASA flight test work has been done on their Boeing 737 Terminal Configured Vehicle (TCV). USAF flight test work has

been done on two T-39 aircraft specifically configured for MLS.

1.3 Scope

This report presents an analysis of the overall control-and-display task for complex trajectory flight using MLS equipment. It reviews the problems and test results of the USAF T-39 program and NASA 737 TCV program as they relate to this subject. It explores the interrelationships of complex trajectory definition and geometry, approach plate design, monitoring, displays and controls. It recommends several electro-mechanical and electronic control-and-display configurations for further investigation via simulation and/or flight test. It also recommends several overall MLS equipment candidate configurations with different levels of complexity which are applicable to the USAF inventory. These configurations have been determined to be appropriate based on studies, contained herein, of 5 representative USAF aircraft: C-130A/D; F-111A/E; A-7D; F-15A; and, KC-10A.

1.4 Summary of Results

To conform to various levels of existing control-and-display capability, four general MLS configurations have been established which encompass the anticipated retrofit requirements for all USAF aircraft. These configurations range in complexity from a direct ILS replacement system, with no capability beyond a straight-in approach, to a full complex trajectory system. The equipment requirements and pilot workload levels associated with these configurations increase proportionally to the MLS capability obtained. Because pilot workload for MLS flight tends to be a determining factor in the level of MLS employed, a significant effort has gone into defining candidate control-and-display configurations which keep workload levels at a minimum. Of particular interest is the MLS-3, Selectable Intercept of Final Configuration. Although it provides only limited complex trajectory capability consisting of a maximum of two lateral and two vertical approach segments, its consequent simplicity for data entry and approach monitoring make it feasible for single-seat aircraft with flight director control. Such feasibility does not exist with a total complex trajectory system for this type aircraft unless automatic data entry and automatic approach coupling are also added. This, of course, greatly increases the retrofit costs. The following

is a brief description of the four MLS configurations:

- MLS-1, Direct ILS Replacement Configuration
 - Angle receiver, C-band antenna, and simple tuner required
 - DME and auxiliary data functions optional
 - No selectable azimuth and elevation angles
 - Raw deviation outputs, identical in format to ILS, are always referenced to the extended runway centerline and nominal glide slope of field
 - Useful for all classes of aircraft
- MLS-2, Selectable Azimuth and Elevation Configuration
 - Required and optional equipment same as for MLS-1
 - MLS tuner required, selection mechanisms for selecting desired azimuth and elevation angles as in Phase III MLS design
 - No low altitude IFR use seen for selectable azimuth function
 - Selectable elevation function useful for STOL and rotary wing aircraft
- MLS-3, Selectable Intercept of Final Configuration
 - Angle receiver, DME interrogator, C-band and L-band antennas and switching unit required
 - Also requires MLS navigation coupler, simple control panel, and AZ/DME display
 - Auxiliary data function optional
 - Provides precise low altitude IFR control along a selectable heading intercept and to a selectable final approach segment length
 - Provides 2-segment glide path capability
 - Allows close-in (less than 2 nm) final approach captures not possible with typical present day ILS approaches (7-10 nm final)
 - Useful for all classes of aircraft
- MLS-4, Complex Trajectory Configuration
 - Requires angle receiver, DME interrogator, and switching unit as in MLS-3
 - Requires fore and aft antennas installations, and antenna switching unit, if desired trajectories warrant
 - Requires more complex MLS navigation computer and AZ/DME display
 - CDU replaces control panel and contains auxiliary

data functions

- A generalized block diagram of the MLS-4 interface with a typical analog flight guidance system is shown in Figure 1.
- Provides precise low altitude IFR control along complex trajectory
- Probably not useful for single-seat aircraft nor two-seat aircraft without automatic approach coupling

The MLS retrofit configuration recommended for each of the specific aircraft considered in this study was greatly influenced by a review of the aircraft's existing control-and-display capability. This review consisted of investigations into each aircraft's: autopilot, flight director, ILS redundancy levels, and primary instrumentation. Pertinent information on the five aircraft is included in the following paragraphs. Table 1 summarizes this information and denotes the recommended MLS configurations for the aircraft.

The autopilots on the F-111A/E, A-7D, and F-15A are "pilot relief" type systems which do not include ILS modes of operation. The autopilots on the C-130A/D and KC-10A do have ILS modes. It should be noted, however, that the C-130A/D flight manual cautions the pilot that continuous monitoring of the system is required below 1000 feet of altitude.

All five aircraft have flight director ILS modes. Raw data from the ILS receiver is displayed on the ADI, HSI, and HUD (for the F-111A/E and A-7D). Flight director commands are displayed on the ADI and HUD. The C-130A/D does not have a pitch steering bar. Instead a 2.5° nose down bias is displayed as a glide slope command on the ADI.

The C-130A/D, F-111A/E, A-7D, and F-15A are essentially Category I aircraft containing a single set of ILS receivers and flight director computers. The KC-10A has dual receivers and computation allowing Category III operation.

The primary instrumentation utilized for navigation and landing on all of these aircraft consists of electro-mechanical indicators. Head-up displays are provided on the F-111A/E, A-7D, and F-15A for final approach guidance. Since the HSI on the five aircraft would be the primary display for situation information during MLS complex trajectory flight, the

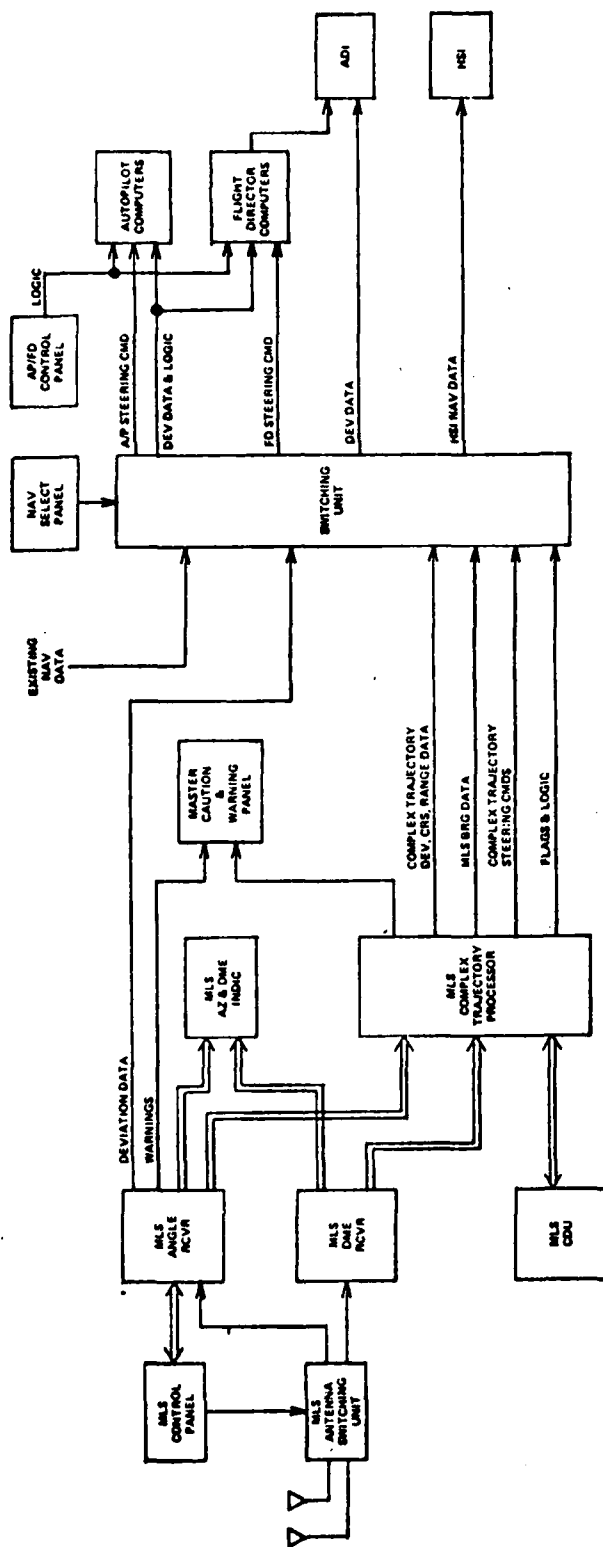


Figure 1 MLS Complex Trajectory Signal Flow

TABLE 1

EXISTING CAPABILITY AIRCRAFT	# OF SEATS	ILS MODE AP/FD	EQUIPMENT REDUNDANCE LEVEL	NAV & LAND INSTRUMENTATION	HSI CAPABILITY				RECOMMENDED MLS CONFIGURATION
					# OF BRG PTRS	AUTOSLEW CRS PTR	HDG BUG	DME READ- OUT	
C-130A/D	2	X	Single	Electro- mechanical	0				MLS - 1
F-111A/E	1	X	Single	Electro- mechanical, HUD	1	X	X	X	MLS - 1
A-7D	1	X	Single	Electro- mechanical, HUD	2			X	MLS - 3
F-15A	1	X	Single	Electro- mechanical, HUD	1	X	X	X	MLS - 3
KC-10A	2	X	Dual	Electro- mechanical	1	X	X	X	MLS - 4

Existing Aircraft Capabilities and MLS Configuration Recommendations

- NOTES: 1. Flight engineer stations exist on the C-130A/D and KC-10A.
2. The F-111A/E is a two-seat aircraft; however, only one seat has access to the MLS-related controls and displays.

functional capabilities of the specific HSIs were considered to be important. Investigations into this instrument for each aircraft revealed the following:

- C-130A/D - No bearing pointer (two RMIs on pilot's instrument panel, however), no autoslew capability of course pointer, no DME readout (separate indicator for TACAN DME)
- F-111A/E - Single bearing pointer, autoslew capability of course pointer and heading bug, DME readout
- A-7D - Two bearing pointers, no autoslew capability of course pointer, DME readout
- F-15A - Single bearing pointer, autoslew capability of course pointer and heading bug, DME readout, digital interface via central computer
- KC-10A - Single bearing pointer, autoslew capability of course pointer and heading bug, DME readout

The recommendation of the complex trajectory configuration for the KC-10A is based on the assumption that the proposed electro-mechanical display presentation and semi-automatic data entry scheme is adequate for safe approach progress monitoring at acceptable pilot workload levels for a pilot/copilot cockpit arrangement. The KC-10A capability of automatic control to touchdown also contributes to the validity of this assumption.

The recommendation of the selectable intercept of final configuration for the F-15A and A-7D is based on the fact that these are single-seat aircraft with only flight director control capability. The simplified data entry scheme of the MLS-3 configuration appears to reduce pilot workload to a reasonable level whereby the close-in approach benefits of this system are achievable in a practical manner. The proposed electro-mechanical display presentation for this configuration is identical to that for the complex trajectory system. Since this configuration basically provides a controlled ILS-type intercept, capture, and tracking maneuver, no problem is anticipated in verifying the adequacy of the display presentation.

The recommendation of the straight-in configuration for the C-130A/D and F-111A/E was primarily due to anticipated retrofit costs. The C-130A/D is an old aircraft with a

control-and-display scheme which does not lend itself to the integration required for complex trajectory flight. The autopilot operation needs improvement, and a vertical axis flight director approach mode does not exist. Further MLS retrofit work done for the C-130A/D should involve consideration of an autopilot/flight director system update. The F-111A/E has a different problem. Although the instrumentation and control capabilities appear to support an MLS-3 configuration, cockpit space is very limited even for the addition of an MLS AZ/DME display. Moreover, even though the F-111A/E is a two-seat aircraft, only the left side contains approach instrumentation.

The assumptions and recommendations herein discussed, are a direct result of the more general complex trajectory analysis efforts included in this report on: trajectory definition and geometry requirements; monitoring and redundancy requirements; display information requirements; and, man-machine interface requirements. From these requirements candidate control-and-display configurations were developed for both present-day and future aircraft. This has resulted in both electro-mechanical and electronic display schemes applicable to complex trajectory flight. Validation of the analysis which generated these candidate configurations can only be achieved via simulation and/or flight test efforts. The following paragraphs summarize this general analysis work.

Complex trajectory definition and geometry requirements are directly related to data entry, approach plate design, and approach monitoring. It is generally accepted that complex trajectories should be defined by straight line segments connected by circular arcs of fixed radii. This is generally accomplished for present-day RNAV systems by defining points in space (i.e., waypoints) in a latitude/longitude/altitude or bearing/DME/altitude format. This method was utilized on both the MLS configured USAF T-39 and NAS 737 TCV aircraft. Significant advantages result, however, if the trajectory is defined as a path extending from the runway touchdown point out to the limits of MLS coverage. By building the trajectory with the magnetic course, length, and flight path angle of each approach segment, the number of data entries are reduced by 30% for an approach consisting of 3 lateral and 2 vertical segments. Moreover, the data required to be entered by the pilot is in a form that is more relatable

to his way of thinking and should, therefore, reduce the probability of entry error.

The design criteria for future approach plates for MLS complex trajectory flight must consider data entry and approach monitoring requirements. The approach plate presentation must contain all the data required to completely define the trajectory to the MLS computer. If this data is based on a trajectory definition which results in minimum data entries and is formatted in a concise manner (e.g., a table), workload will be reduced. Several different 3-D approach plate designs were investigated as part of the analysis effort. These have definite advantages for complex trajectory flight since they combine both the lateral and vertical profiles in one overall view of the approach. This will probably aid the pilot in approach monitoring. One disadvantage occurs in that it is impossible to retain a north-up relationship for approaches which run close to north or south. Rotating the situation to provide a better vantage point for the perspective view may or may not be acceptable to the users. Further evaluation of this subject must be conducted with pilots, traffic controllers, and TERPS personnel.

Complex approach monitoring involves the pilot's use of display information and/or equipment redundancy to detect the presence of both gross and subtle failures. Possible sources which can introduce these failures include the pilot, CDU, MLS computer, and displays. Like Category III ILS equipment, the MLS transmitter/receiver is assumed to be self-monitored. Unlike ILS, however, the MLS receiver outputs are not always easily interpretable with respect to the path being flown. Depending on the approach, all three parameters may be constantly changing during the complex portion. The MLS data corresponds to the ILS information only during the final approach segment.

Data entry errors involving the pilot, CDU, or computer are detectable via a semi-automatic check procedure which must be performed by the pilot. After entering the required trajectory data, the pilot enters an along-track-distance corresponding to a check point shown on the approach plate. Based on this distance and the newly computed trajectory, the computer calculates the check point's azimuth, DME, and elevation. The pilot then verifies this data, shown

on the CDU, against the corresponding data shown on the approach plate. Any difference indicates an entry error or failure.

Gross failures which occur during the complex portion of the approach are detectable with the primary instruments (e.g., ADI, HSI, rate of climb). Subtle failures during the complex trajectory will probably go undetected until the final approach segment unless some form of automatic monitoring is employed. Monitoring on an MLS final approach is virtually identical to ILS except for the addition of DME. If the complex portion of an IFR approach is considered flight critical due to obstacle avoidance or for any other reason, equipment redundancy is probably required. Procedures for missed approaches, due to partial or complete loss of MLS data, must be carefully established for complex trajectories in obstacle areas. Simulation and/or flight test studies are required to determine the adequacy of these procedures during operations in both high and low traffic environments.

The display information presented to the pilot for complex trajectory flight must be sufficient for:

- Controlling the aircraft about the desired path
- Monitoring system operation and performance
- Maintaining orientation with respect to the path and the runway

Also the information must be presented in an integrated format to result in acceptable pilot workload levels. The recommended complex trajectory display parameters, computational source, and indicator type are shown below:

	<u>SOURCE</u>	<u>MLS</u>	<u>ADI</u>	<u>HSI</u>	<u>CRT</u>
AZIMUTH ANGLE	RCVR	X			X
RANGE-TO-GPIP	RCVR	X			X
LAT DEVIATION	RCVR/CMPTR			X	X
VERT DEVIATION	RCVR/CMPTR		X		X
DESIRED TRACK ANGLE	CMPTR			X	X
RANGE-ALONG-TRACK-TO-GPIP	CMPTR			X	X
BEARING-TO-STATION	CMPTR			X	X

	<u>SOURCE</u>	<u>MLS</u>	<u>ADI</u>	<u>HSI</u>	<u>CRT</u>
PATH ANTICIPATOR	CMPTR			X	X
FLIGHT PATH ANGLE	CMPTR		X		X
MAP DISPLAY	CMPTR				X
PREDICTOR	CMPTR				X

For an aircraft with electro-mechanical instrumentation, an MLS AZ/DME indicator is required as a computer-independent display of aircraft position. This display will be useful for monitoring approach progress and MLS operation. A typical example of the complex trajectory display format using electro-mechanical instrumentation is shown in Figure 2. For future aircraft with primary electronic displays, all information can be integrated within one CRT-type indicator. Figures 3 and 4 depict two color CRT display formats which have been devised for MLS complex trajectory flight. Although the static presentations appear to be quite "busy", it is felt that operation in a true and/or simulated dynamic environment will result in pilot acceptance.

The man-machine interface problems with MLS flight are basically associated with the workload requirements of complex trajectory data entry. Because automatic data entry is an expensive alternative in terms of both initial purchase cost and recurring logistics costs, manual data entry will probably be used on a widespread basis until an inexpensive ground-to-air transponder system is perfected which can accomplish this task. Even then a back-up manual entry scheme will be required. Manual data entry for MLS, like for RNAV, is accomplished with a CDU. For retrofit aircraft it is anticipated that a new MLS CDU will be incorporated. For future aircraft the MLS functions can be easily incorporated into an integrated multifunction keyboard and controller. Basic CDU requirements include the need to design logic which: leads the pilot to the data which has to be entered; minimizes operations; and, is simple to use. The unit should also utilize terminology which is familiar to the pilot. A typical MLS CDU is shown in Figure 5. It integrates all the control functions (except the ILS/MLS selection switch) associated with MLS complex trajectory flight into one unit. These functions include:

- Data Entry
- Channel Select
- Audio Volume Select
- Antenna Mode Select
- Complex Trajectory Mode Select
- Auxiliary Data Select

For the proposed configurations which do not fully utilize the total MLS complex trajectory capability, there is a significant decrease in control function complexity. The data entry task is considerably reduced for the MLS-2 and MLS-3 configurations, and is completely eliminated for MLS-1. This, by itself, reduces pilot workload for approach set-up procedures to a level which closely approximates that for ILS. Figure 6 depicts typical panels for the direct ILS replacement, selectable elevation and azimuth, and selectable intercept of final MLS configurations.

1.5 Report Organization

The remainder of this report presents information in the following order:

- Section 2.0 contains a discussion of the problems associated with MLS complex trajectory flight and its relationship with USAF requirements.
- Section 3.0 presents overall design criteria for complex trajectory flight. This includes detailed discussions on trajectory definition and geometry requirements, monitoring and redundancy, display information parameters, and man-machine interfaces.
- Section 4.0 presents candidate control-and-display configurations for four levels of MLS capability. This information has been generalized to make it applicable to present and future aircraft within the USAF inventory. As a result information is presented for both electro-mechanical and electronic display schemes.
- Section 5.0 presents the results of studies conducted on five specific USAF aircraft. For the C-130A/D, F-111A/E, A-7D, and F-15A, technical orders for the systems related to an MLS retrofit were reviewed.

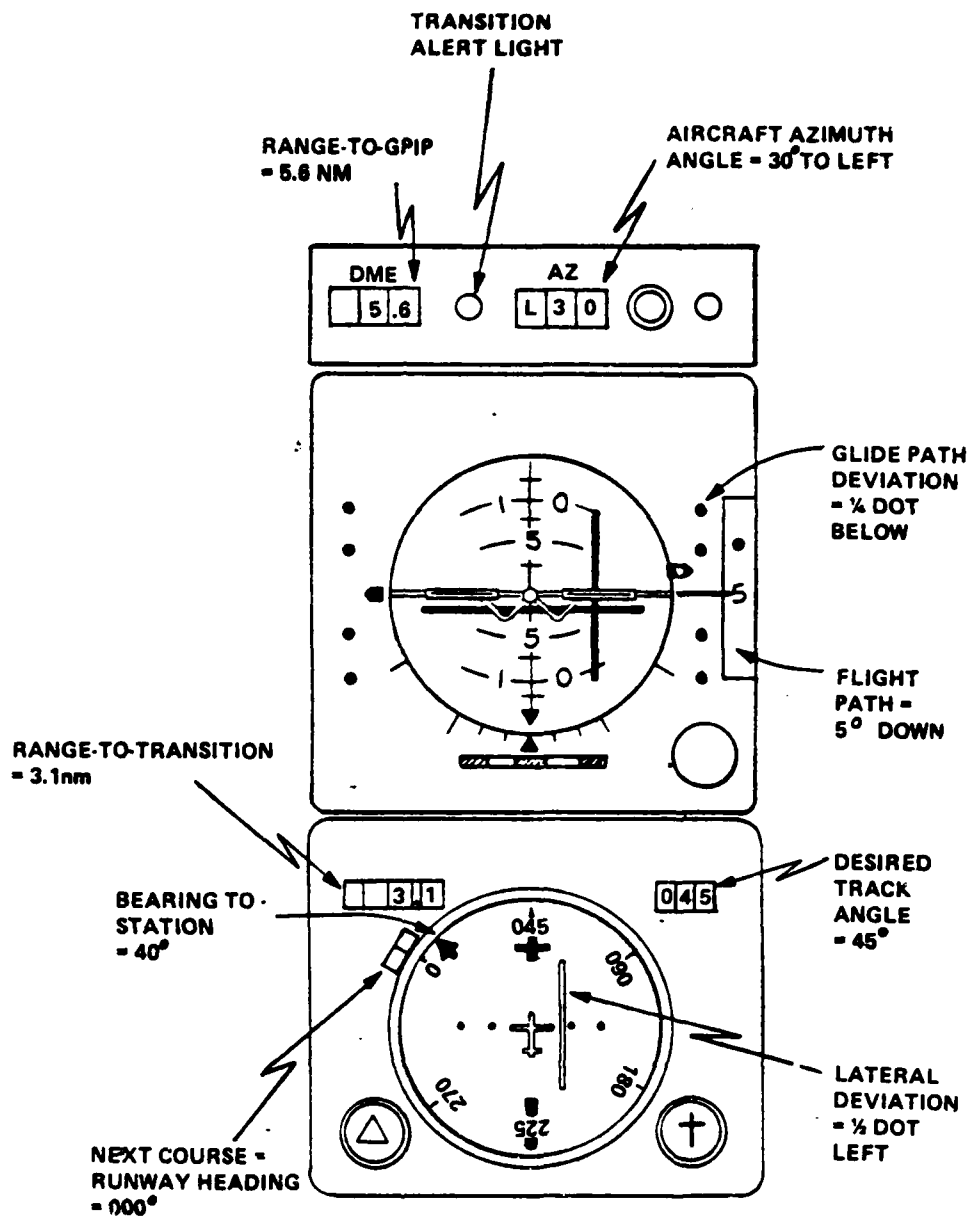


Figure 2 Typical Complex Trajectory Electro-Mechanical Instrumentation

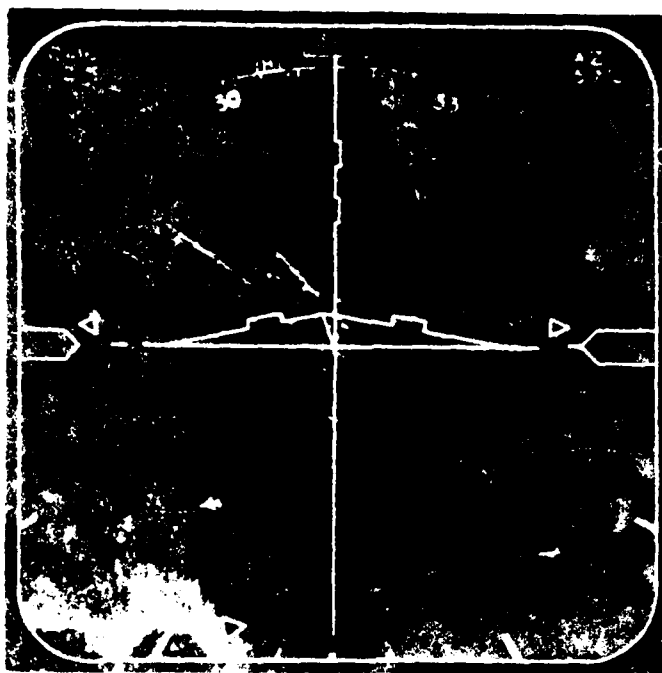


Figure 3. 3D Color Display

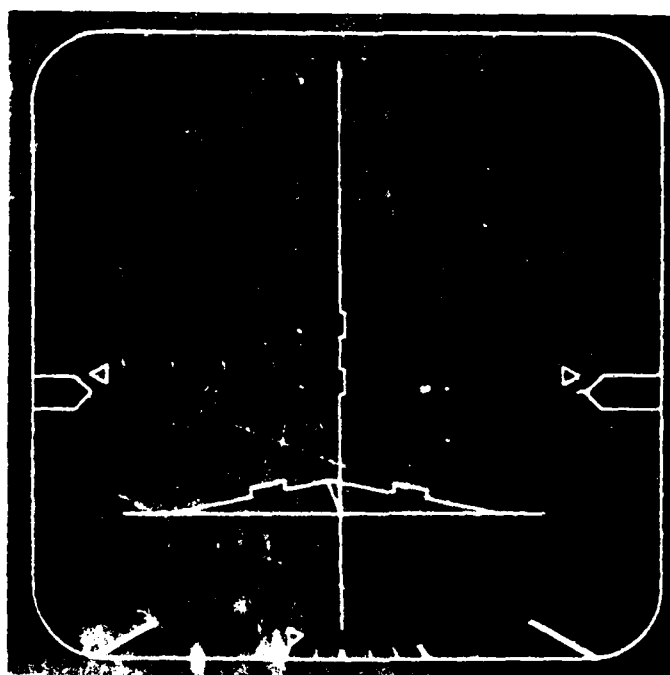


Figure 4. 2D Color Display

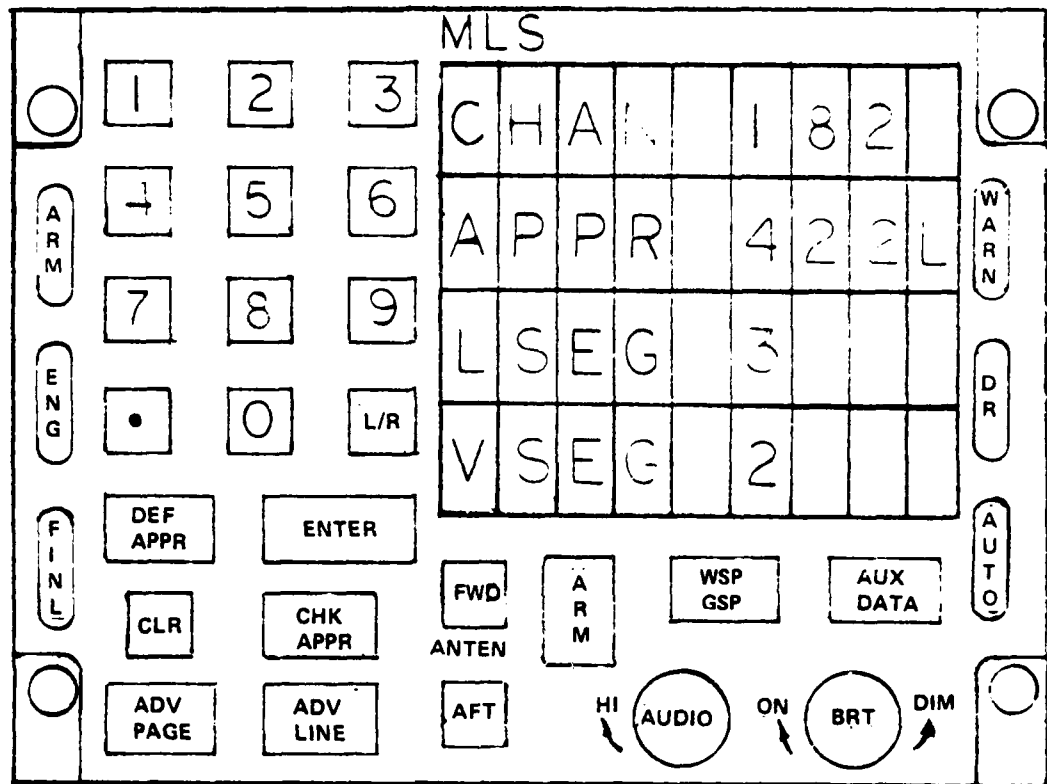
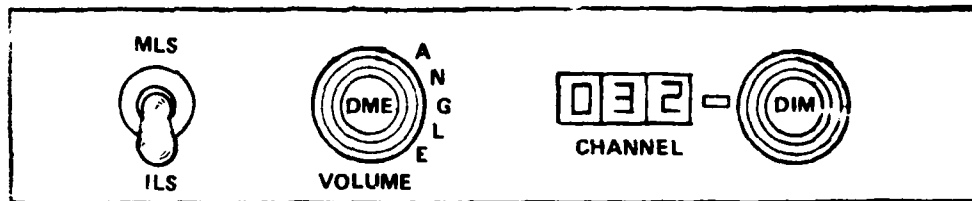
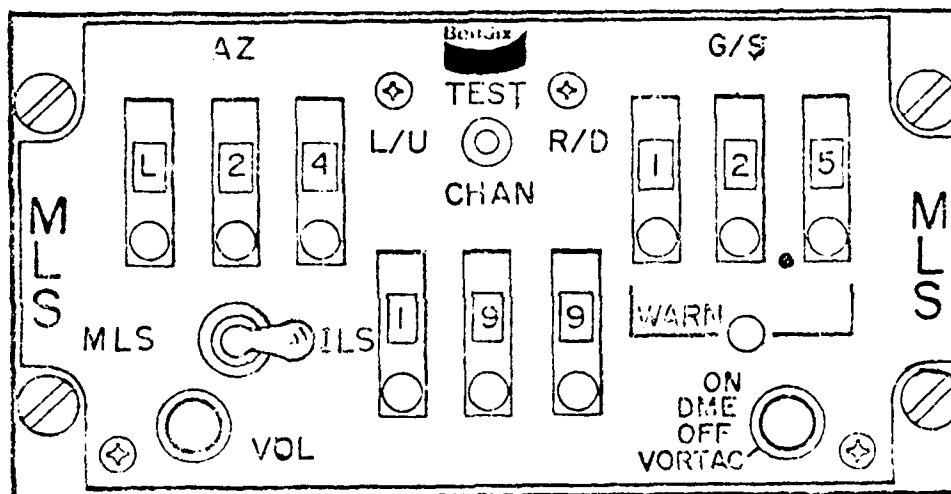


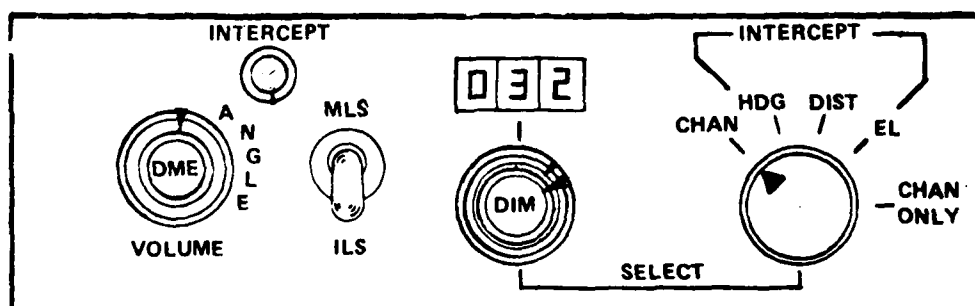
Figure 5 Typical Complex Trajectory CDU



MLS-1, Direct ILS Replacement Tuner



MLS-2, Selectable Azimuth And Elevation Tuner/Selector



MLS-3, Selectable Intercept Of Final Controller

Figure 6 Typical Panels For General MLS Configurations

For the KC-10A, information was obtained from McDonnell-Douglas directly since T.O.s do not exist. This information was compiled and is included to provide a description of the existing aircraft. Based on this, MLS configuration recommendations are included for each aircraft.

- Section 6.0 presents proposed issues associated with a design definition phase activity. These issues require further concept refinement and evaluation in a closed-loop cockpit simulator environment.
- Appendix A contains a list of references obtained during a background survey for this investigation.
- Appendix B provides an analytical insight into the role of a predictor in an electronic horizontal situation display.
- Appendix C presents an overview of the USAF T-39 MLS and NASA TCV programs as they relate to the subjects of this study. Also included are synopses of several other studies which are applicable to the subject matter contained herein.
- Appendix D presents an overview of various 3-D image representations of MLS complex trajectories. It also presents general design criteria for a 3-D display format.
- Appendix E contains a detailed task description of the pilot procedures involved with flying and monitoring an MLS complex trajectory approach on the USAF T-39. The procedures are based on the T-39 with electro-mechanical instrumentation rather than the one with the electronic display.

2.0 DISCUSSION OF THE PROBLEM

2.1 Description of MLS

MLS is an all-weather landing system consisting of ground and airborne transmitter/receiver equipment. It provides precise high-integrity guidance signals over a wide coverage sector. These signals are relatively unaffected by topography, airport structures, overflying and taxiing aircraft, ground vehicular traffic, and weather. MLS ground equipment can be deployed in remote, generally hostile physical environments and will provide basic high reliability performance (MTBF \approx 1000 hrs) with minimal attention (MTTR \approx .36 hrs.)

A total MLS, in its most expanded present form (FAA Phase III MLS), consists of:

- Ground Transmitters (typically laid out as shown in Figure 7)
 - Front and back azimuth phased array antennas
 - Approach and flare phased array antennas
 - Precision L-band DME antenna
- Airborne equipment (excluding complex trajectory computational and control/display requirements)
 - C-band angle receiver, nose and tail omnidirectional antennas, and antennas switching unit.
 - L-band DME interrogator and antenna
 - Control panel, as shown in Figure 8. for selection of MLS channel, azimuth and elevation angle
 - Auxiliary data panel, as shown in Figure 9 for display of ground transmitted parameters such as runway heading and condition (wet or dry), transmitter operational status (CAT I, CAT II, CAT III), and minimum glide path for the runway.
 - DME indicator

MLS provides many advantages over the present day ILS. These advantages include:

- Greatly increased volumetric data coverage
 - 1° to 20° of elevation data vs. a $3^{\circ} \pm 0.7^{\circ}$ glide slope.

4.1.1.1
4.1.1.2
4.1.1.3
4.1.1.4

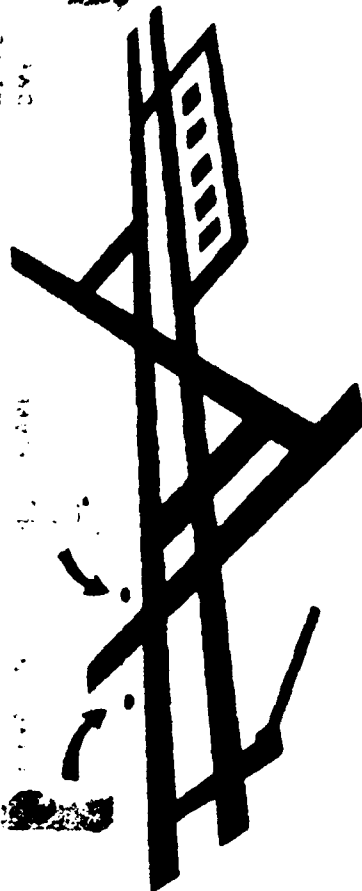


Figure 7 MLS Ground Equipment

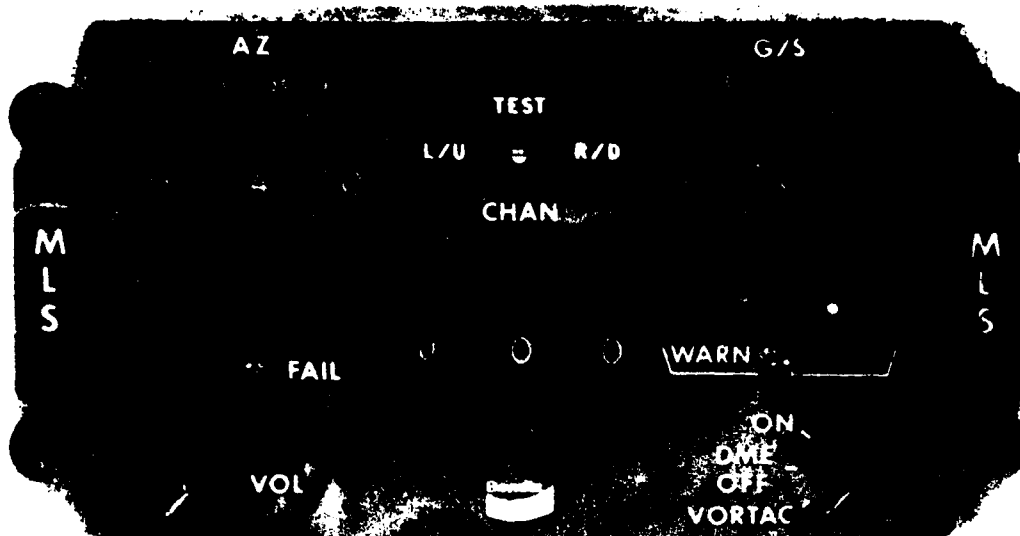


Figure 8 Phase III MLS Control Panel

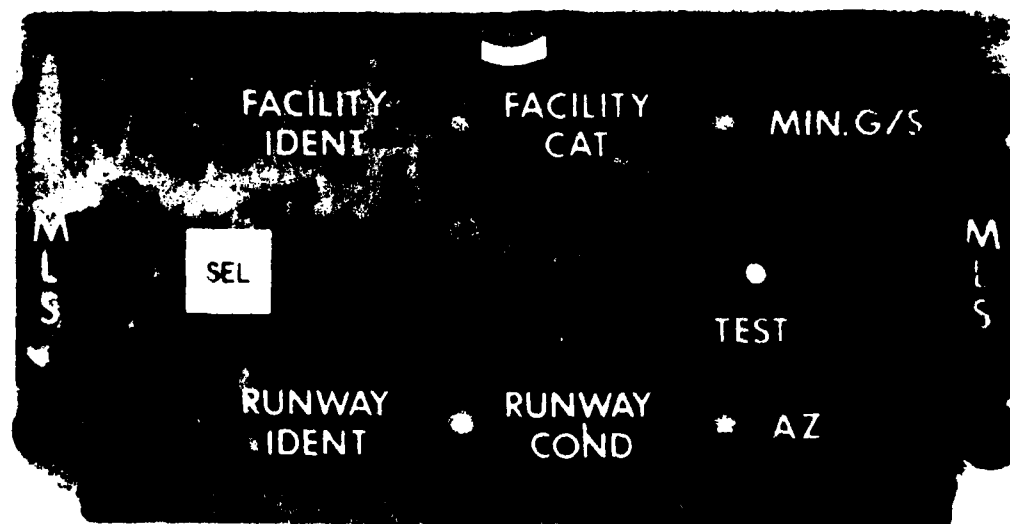


Figure 9 Phase III MLS Auxiliary Data Panel

- $\pm 60^\circ$ of azimuth data vs. a $\pm 2^\circ$ localizer
- Angle guidance and precision DME to a range of 20 nm
- Back azimuth guidance of $\pm 40^\circ$ to a range of 5 nm
- A receiver data format that provides a digital output for aircraft position as an absolute azimuth and elevation angle, as well as analog outputs (like ILS) for angular deviation about the selected azimuth and elevation angle.
- Increased data accuracy and improved signal quality
 - Eliminates low frequency beam bends inherent with the ILS
- Missed approach and take off guidance
- Derivation of a terrain -independent altitude above the ground which can be used to improve the flare control law.
- 200 frequency channel capability as opposed to 80 for ILS
 - MLS operates from 5031.00 to 5090.10 to MHz with 300 KHz spacing

From the MLS absolute angular position and DME data, an on-board digital "MLS navigation computer" (this may be an existing RNAV or flight control computer; or it may be a new computer dedicated to MLS guidance) can precisely compute present aircraft position in rectangular coordinates, compare it to a predefined path with respect to the ground, develop guidance commands and/or error signals, and thereby result in aircraft control about a complex trajectory.

2.2 Complex Trajectory Flight

Two examples of complex trajectories flown by the USAF T-39 at the National Aviation Facilities Experimental Center (NAFEC) in Atlantic City, N.J. are shown in Figures 10 and 11. Each approach is made up of a series of waypoints connected by straight-line segments beginning outside MLS coverage under VORTAC or RNAV guidance and ending at the missed approach point. Transitions between straight-line segments are made about circular arcs of fixed radii.



Figure 10 MLS Complex Trajectory -- MLS RWY13-153

MLS RWY13-253

ATLANTIC CITY APP CON
 448 303.5
 ATLANTIC CITY TOWER
 89 230.0
 AND CON
 3 9 304.6
 ASD

NAPEC ATLANTIC CITY

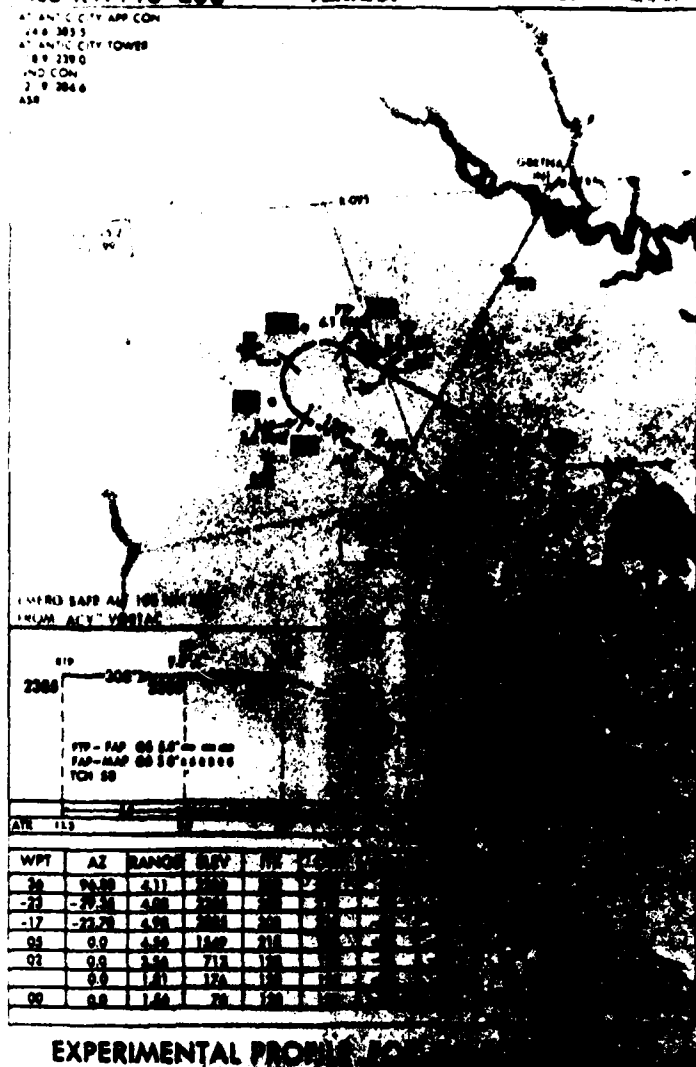


Figure 11 MLS Complex Trajectory -- MLS RWY13-253

In general, an infinite number of complex approach profiles can be described within the wide MLS data coverage. Multi-segmented paths can be defined in both the lateral and vertical axes. Control of the aircraft about these paths can result in:

- Increased terminal air traffic density
 - A reduction in aircraft landing times via 90° intercepts to short final approach lengths (six miles or less)
 - More efficient sequencing of aircraft by having high and low speed aircraft fly different approach paths to the airport so that the faster aircraft can effectively "pass" the slower aircraft
- Effective noise abatement procedures by defining profiles which avoid population centers and by utilizing two or even three segment descents.
- Obstruction avoidance whereby aircraft can fly into airports not serviceable by ILS due to the position of mountains.
- Ground fire avoidance whereby the military can avoid flying over known enemy territories and can minimize risk by flying dissimilar approaches.

2.3 Control-and-Display Issues

The difficult problems encountered with complex trajectory flight in the terminal area primarily relate to pilot workload and air traffic control considerations. They are not associated with implementing autopilot and flight director control law equations to accurately fly the desired path. MLS control laws developed for the T-39 utilizing crosstrack deviation, and track angle error and ground speed to derive crosstrack deviation rate, in the lateral axis; and utilizing vertical track deviation and rate, derived in a complementary filter scheme using vertical speed and normal acceleration, in the vertical axis - provided a smooth transition into MLS coverage, an immediate capture of the first MLS segment and accurate tracking throughout the approach. The problems in attaining Category II and III performance levels for landing appear to be easier to solve for MLS than for ILS due to the quality of the signal.

Problems, which require further study and which will be discussed in various levels of detail within this report, relate to:

- Pilot workload- the pilot's ability to perform the necessary tasks to: define the desired trajectory to the computer; actuate and maintain control of the aircraft via the flight director or autopilot MLS mode; continuously monitor his situation using the available displays; and, detect failures quickly.
- Display information requirements and integrated display presentation formats to result in acceptable levels of pilot workload throughout the maneuver.
- Trajectory definition to the computer and its relationship with the approach plate format and pilot monitoring techniques.
- Entry procedures into MLS coverage including transitions from RNAV, TACAN, VNAV and altitude hold.
- Equipment redundancy requirements during the complex portion (i.e., other than the straight-in final segment) of an IFR approach which may involve obstacle or ground fire avoidance.

Other problems which require further study but are not discussed in significant detail within this report involve:

- Air traffic control procedures to take maximum advantage of MLS without any sacrifice in safety.
- Accuracy requirements during the straight line segments and circular arc transitions of the complex portion of the approach.
- Missed approach procedures during the complex portion of the approach.
- Improvements in autoland control laws through the use of terrain independent altitude, ground speed and wind speed information derived from MLS.

2.4 MLS Integration in USAF Inventory

2.4.1 Review of GOR

A "General Operation Requirement (GOR) for an Advanced Landing System (ALS)" has been defined by the Department of the Air Force per AFCS 702-78. It addresses the operational deficiencies of the present generation of precision approach and landing systems (PAR and ILS) used by USAF aircraft; and, it establishes requirements which, when implemented, will correct these deficiencies. The GOR has not been validated by HQ USAF and some format and content changes can be expected in the eventually approved requirements document. The following is a review of the GOR as it pertains to this study.

Neither Precision Approach Radar (PAR) nor ILS can provide a true zero visibility landing capability without great expense, nor can they provide any significant degree of approach path flexibility. Since ILS ground systems are physically large and are extremely sensitive to their physical environment, ILS is not suitable for general use in tactical situations. Although PAR is not as severely limited by siting constraints, it is a highly complex system with high acquisition, installation, operation and maintenance costs. PARs are limited in range (9 nm for present-day systems and only up to 20 nm for the TPN-19), are unable to perform to Category III criteria, and have extreme difficulty in performing to Category II. The ALS is required to overcome these deficiencies and support various levels of operational missions with various levels of performance requirements.

At the lowest level, the ALS should provide ICAO Category I service and a quick set-up capability to satisfy short term contingency requirements or other limited operations. These include operations at:

- An Assault Landing Zone consisting of a sufficiently level field or clearing of a size to permit landings by tactical aircraft, forward air control and rotary wing aircraft. The area may be camouflaged and only primitive area markers would be present.
- An Extraction Zone consisting of an open field or clearing to permit cargo aircraft flyovers at approximately ten feet above ground level (AGL).

- A Drop Zone, possibly in the vicinity of rough terrain, whereby cargo aircraft approaches and airdrops may be conducted as low as 50 feet AGL.
- Locations where frequent helicopter activities are required for combat rescue, medical evacuation, and selective airlift.

Limited operations ground equipment should provide: $\pm 20^\circ$ of azimuth coverage and 1 to 15° of elevation coverage to a range of 10 nm. Back course coverage is not required.

At the second level, the ALS should provide ICAO Category II service (expandable to Category III) for tactical operations. Tactical operations will typically be conducted in a bare base environment at site which has evolved from the build up of a limited operations site. Aircraft operations will normally include tactical fighters, medium transports, and helicopters. RPVs may also be present. Although only a single runway (typically 2,000 to 12,000 feet in length) may be available, operations must support high recovery rates. Curved approach paths may be used to avoid hostile fire areas and for traffic separation.

Tactical operations ground equipment should provide $\pm 40^\circ$ of azimuth coverage and 1 to 20° of elevation coverage to a range of 20 nm. Back course coverage of $\pm 40^\circ$ should be provided to a range of 5 nm.

At the highest level, the ALS should provide ICAO Category III service for full scale operations. These operations would be typified by a main base with parallel runways of up to 15,000 feet and servicing all aircraft types. High aircraft recovery rates (one per minute per runway) could be expected on the parallel runways separated by not less than 2500 feet. Curved approach paths may be used to aid in traffic control and for avoiding selected areas of the approach and departure sectors which would result in a flight path over densely populated residential areas.

Signal coverage of the ground equipment installed for full scale operations is identical to that described above for tactical operations.

Three levels of ALS avionics equipment were considered in the

GOR and were related to the various aircraft types as follows:

- 1) Austere Avionics: Cost would be a primary consideration in this avionics configuration; however, the equipment must be capable of providing the equivalent of ICAO Category I service. Cost considerations may dictate that range information be provided by the TACAN/DME system. The mission of aircraft in this category would primarily be conducted in VFR conditions. Some types of attack (A-10), trainers (T-37), and utility aircraft would use this category of equipment. May be combined with Standard Avionics so that only two categories of Avionics exist.
- 2) Standard Avionics: Capable of ICAO Category II approaches in IFR conditions. Classes of aircraft requiring avionics in this category would include some of the cargo aircraft (C-130), the heavy bombers (B-52), tankers (KC-135), most fighters, and advance trainers (T-38).
- 3) Advanced Avionics: Capable of Category IIIA, B, and C approaches and landing. Aircraft requiring avionics in this category would include some of the cargo aircraft (C-5, C-141), air defense interceptors, and RPVs.

In general, it was stressed that aircraft with any level of ALS avionics should be capable of landing at any field with ALS ground equipment to at least, the performance criteria associated with the lowest level of ground or airborne equipment capability.

2.4.2 General MLS Retrofit Assumptions and Considerations

The integration of MLS into an existing aircraft, in the most cost-effective manner, is a difficult problem. Tradeoffs, relating to a cost-effective design, must address the possibilities of: adding new computers, displays, and panels; modifying existing computers, displays, and panels; replacing old units with new units which contain both the old and new functions; or, some optimum combination of all of these. This study has not attempted to provide a detailed analysis of these combinations.

For this study it has been theorized that a cost-effective MLS retrofit of USAF aircraft will not result in significant philosophy and/or configuration changes for the particular aircraft. That is, MLS modes of operation will not be added to autopilots which do not presently have ILS modes; dual redundant MLS receivers will not be added to configurations which presently incorporate single ILS receivers; and, present electro-mechanical instruments will not be replaced with electronic CRT type equipment. New information requirements for MLS complex trajectory flight will be both integrated into existing displays via switching and presented on a new display if cockpit space permits. These compromises are felt to be required to remain within the probable retrofit budget constraints.

For these reasons, the level of complex trajectory capability possible with the various aircraft will depend primarily on the aircraft's existing level of automation and display. This was shown in the USAF/T-39 Program by comparing complex approaches made with standard flight director steering commands and those made using autopilot control. The workload associated with controlling power settings, maintaining orientation and monitoring instrumentation for failures while manually flying command bars was determined to be excessive during complex maneuvers using standard electromechanical displays. With autopilot control, however, workload was greatly reduced to the point whereby better display and control function integration could result in pilot acceptability. Since, of the aircraft being studied, only the KC-10A and C-130 have autopilot approach modes; it might be assumed that only these aircraft would be able to fly MLS complex trajectories. This is not necessarily true, however, since a reduction in the level of complex trajectory flight may obviate the need for an autopilot.

For example, an approach consisting of a 90° intercept to a short final leg with a constant 3° glide slope descent, may result in acceptable pilot workloads with only flight director control. A short final type of an approach, while not fully utilizing MLS capabilities, may provide significant advantages for getting fighter and attack aircraft on the ground in minimum amounts of time and at recovery rates consistent with the ALS GOR.

Table 2 shows the benefits obtained from the wide MLS

coverage in terms of the ability to perform 90° intercept captures of the final approach segment very close to the runway threshold. Shown, for comparison purposes, is turn rate data with respect to: a typical $\pm 2^\circ$ ILS localizer; a civil $\pm 10^\circ$ small community MLS; a limited operations military $\pm 20^\circ$ MLS; and, a $\pm 40^\circ$ MLS. The data consists of the maximum aircraft speed at which the maneuver can be successfully accomplished, with minimal overshoot of the extended runway centerline, using maximum bank angles of 30° and 45° . Also shown as part of the data is the distance to the runway threshold after the aircraft has rolled out on to the final approach segment; and, the maximum altitude at which the maneuver can occur if the aircraft is to remain on, or below, a 3° glide slope beam. The maneuver could also be performed as a descending turn using a glide path angle greater than 3° for the initial descent on to final.

From the data it can be seen that the localizer geometry does not allow this type of maneuver, even when travelling at 120 knots, unless the aircraft is 10 or more miles from the runway threshold. Contrary to this, a 2 nm capture is possible at 140 knots with the narrow $\pm 10^\circ$ MLS beam. With the $\pm 20^\circ$ MLS beam, 90° intercepts can be performed by even high approach speed aircraft 2 nm from the runway threshold.

In Section 4.1 a general MLS control-and-display configuration is described which takes advantage of the wide MLS coverage to the extent specified here. It provides precise guidance over any selectable intercept angle to a selectable final approach distance. It also allows selection of a two-segment descent profile.

3.0 COMPLEX TRAJECTORY FLIGHT CONTROL-AND-DISPLAY

DESIGN CRITERIA

3.1 Complex Trajectory Geometry Definitions and Requirements

3.1.1 Possible Trajectories

Ideally the MLS allows for the use of any complex trajectory which can be mathematically defined. However, at present, there appears to be no mission requirements which can not be satisfied by trajectories composed entirely of straight line segments and circular arcs in the vertical and horizontal planes.

This simplification in requirements is significant from several aspects. First, and perhaps foremost, is that it allows the approach plate designer relatively simple calculations to define and illustrate the horizontal track. This also allows simple calculations for vertical path transitions which must be specified first in terms of along track distance (although they may be shown on the approach plate in many other ways). Along track distance (ATK) is defined as the distance along the trajectory measured in the horizontal plane. The reference point for this measurement is the GPIP (Glide Path Intercept Point), which is the point on the runway where the glide slope extension intercepts the runway.

Secondly, this simplification is carried over into the MLS computer which now has only restricted types of trajectories to compute from the input data, i.e., there are only straight line segments connected by circular arcs.

The greatest drawback to confining the trajectory geometry in this manner is that it is physically impossible for an aircraft to fly these trajectories exactly. For instance, the transition from a straight horizontal track segment to a horizontal circular arc requires an infinite roll rate if no error is to occur. Similarly, in the vertical plane, an infinite rate of normal acceleration is required.

TABLE 2

* SPD/BANK ANGLE/FINAL APPR LENGTH/MAX. ALTITUDE AFTER ROLLOUT TO BE ON OR BELOW 3°GS

RANGE TO THRESH (NM) ALONG FINAL HDG AT 90° INTERCEPT	2° BEAM WIDTH		10° BEAM WIDTH		20° BEAM WIDTH		240° BEAM WIDTH	
	10,000'	7,000'	10,000'	7,000'	10,000'	7,000'	10,000'	7,000'
1	NOT ATTAIN- ABLE(NA)	NA	NA	NA	140KT/30°/0.51NM/162° 180/45/0.53/168	→	→	→
2	NA	NA	140/30/1.51/480 180/45/1.53/487	130/30/1.57/501 170/45/1.58/503	200/30/0.99/315 200/45/1.42/451	190/30/1.09/347 200/45/1.42/451	200/30/0.99/315 200/45/1.42/451	→
3	NA	NA	150/30/2.43/775 190/45/2.47/788		200/30/1.99/634 200/45/2.42/700	→	→	→
4	NA	NA	170/30/3.27/1042 200/45/3.41/1086		200/30/2.99/853 200/45/3.41/1086	→	→	→
5	NA	NA	190/30/4.09/1302 200/45/4.42/1407		200/30/3.99/1271 200/45/4.42/1407	→	→	→
6	NA	NA	200/30/4.49/1590 200/45/5.42/1726		→	→	→	→
10	120/45/9.79/3119		200/30/8.99/2864 200/45/9.42/3000		→	→	→	→
15	120/30/14.6/4663 160/45/14.6/4660		200/30/14.0/4458 200/45/14.4/4594		→	→	→	→
20	150/30/19.2/6130 180/45/19.5/6222		200/30/19.0/6051 200/45/19.4/6187		→	→	→	→

Speed/Bank Relationship for 90° Intercepts of Final

These limitations are overcome by precognitive cues which cause the changes to start earlier, and although errors are not zero, they are sufficiently small to satisfy the accuracy requirements. It must also be remembered that during the final leg of an approach, at least twenty to forty seconds of straight flight are required to allow the pilot to orient himself and to assess the validity and accuracy with which final touchdown will occur.

3.1.2 Radius of the Circular Arc

Two basic questions arise relative to the circular arc paths. First, should the arc radius be defined on the approach plate or should it be left to the pilot's discretion to select? It is most desirable to show both the vertical and the horizontal transition points on both the vertical and horizontal projections of the approach plate. If the turn radius is changed, the ATK to every point preceding the turn is changed. As a result, the vertical transitions are shown erroneously on the horizontal projection and the horizontal transitions are shown erroneously on the vertical projection. This consideration alone is a sufficient reason to require that a specific approach plate shall show a prescribed radius for every turn.

This problem is illustrated in Figures 12a and 12b. Figure 12a shows the horizontal and vertical profiles for a typical approach with a three degree glide slope angle, and a 123 degree turn of one mile radius. Note that the descent is initiated while in the turn.

Figure 12b illustrates the same approach but utilizes a two mile turn radius. Note that every transition point has moved with respect to the GPIP and that the descent is now initiated before the turn. Basic MLS azimuth, elevation, and range data which might be given for checks along the trajectory (data not shown in the figure) are vastly different for the two trajectories. In addition, the ATK for the horizontal transitions have changed in a manner too complicated for the pilot to compute in a reasonable amount of time.

In summary, if the pilot is given an approach plate corresponding to a prescribed radius of turn and he changes that radius when defining the trajectory to the MLS computer, the resulting trajectory will, in general be very different in many aspects. These differences will make the information on the approach plate virtually useless for the purpose of monitoring the progress and the accuracy of the approach.

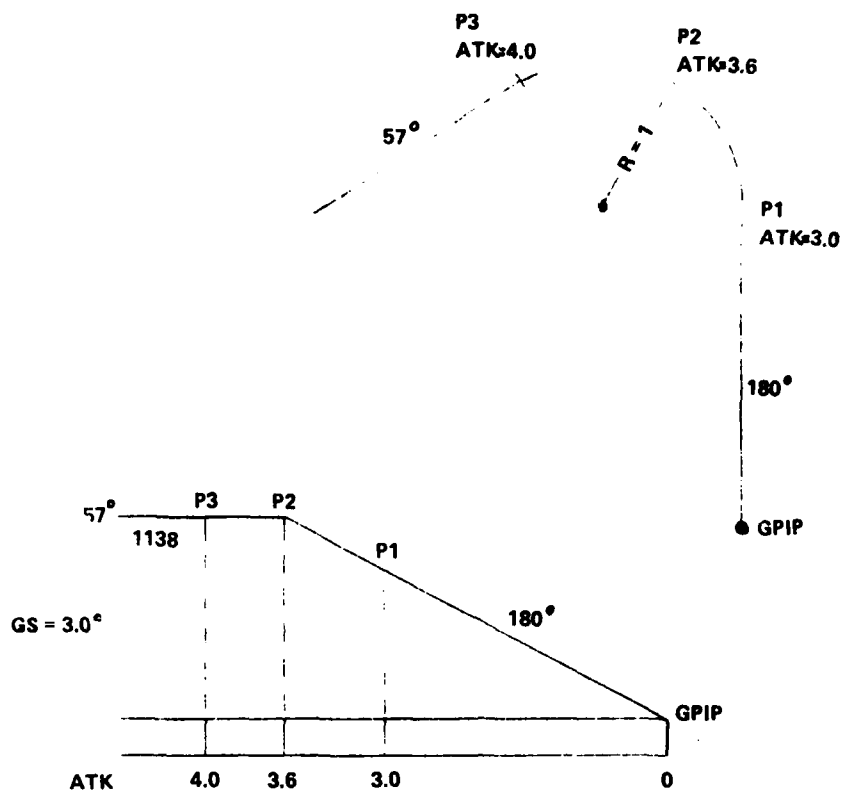


Figure 12a Radius Of Turn One Mile

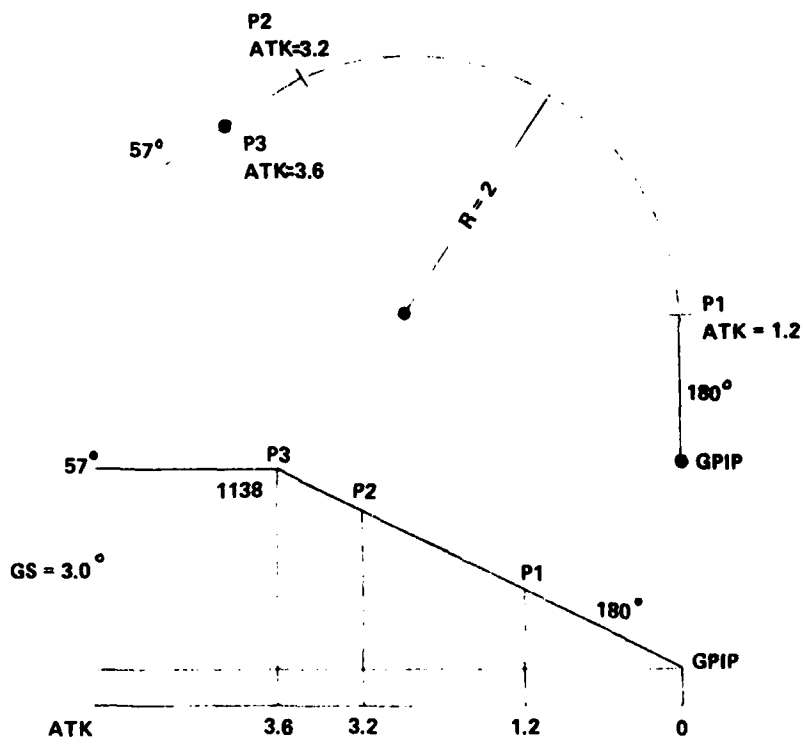


Figure 12b Radius Of Turn Two Miles

Figure 12 Effect Of Change In Turn Radius

The next logical question is what should be the prescribed radius of turn. The turn should correspond to the smallest bank angle (largest turn radius) consistent with traffic which result in significant coupling of horizontal and vertical motion are discouraged. Since the bank angle required to fly a particular circular arc varies with the square of the approach speed, designers must consider the type of aircraft to be flying the approach when defining the trajectory's radius of turn. This characteristic is shown in Figure 13 for two different radii.

Bank angles of less than 30 degrees are required to track a 1 nm radius of turn at approach speeds of 180 knots or less. For speeds up to 240 knots, a 2 nm radius is required to hold bank angles below 25 degrees. Due to these performance limitations, several trajectories with different radii will be required for landing zones which are used by both high and low speed aircraft. The alternative is to define all the trajectories for the high speed aircraft thereby penalizing the low speed aircraft in terms of approach maneuverability.

The same basic criteria hold true for transitions in the vertical plane. In the absence of other overriding criteria, a trajectory should be defined which corresponds to about .05 g's at normal approach speeds.

The same type of variation due to speed occurs in the vertical plane insofar as normal acceleration is concerned, as depicted in Figure 14. From these figures it becomes apparent that low speed aircraft (e.g., STOL) are, in particular being severely limited by restricting their flight to the same maneuvers as CTOL aircraft. For this reason, and because STOL aircraft will be subject to different traffic control considerations, it would be advisable to provide additional approach plates for the exclusive use of STOL aircraft. These approach plates would provide sharper turns, more rapid changes in flight path angle, and of course the steeper descent angles for which these aircraft have been designed.

In any event, it is important that, for all aircraft types, all transitions have been completed and that stabilized straight-in-flight has been established before the decision height is reached.

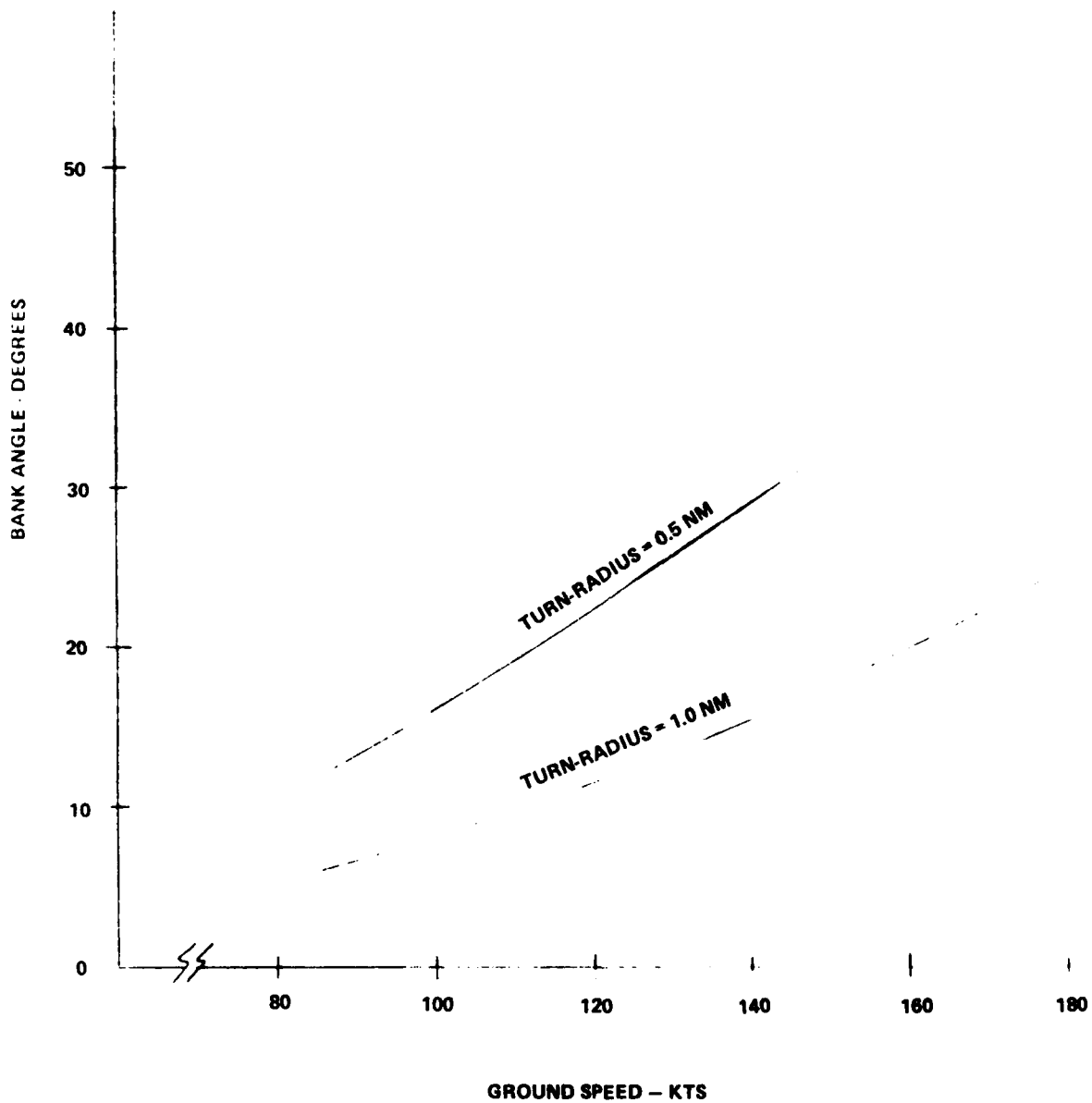


Figure 13 Variation of Required Bank Angle With Speed

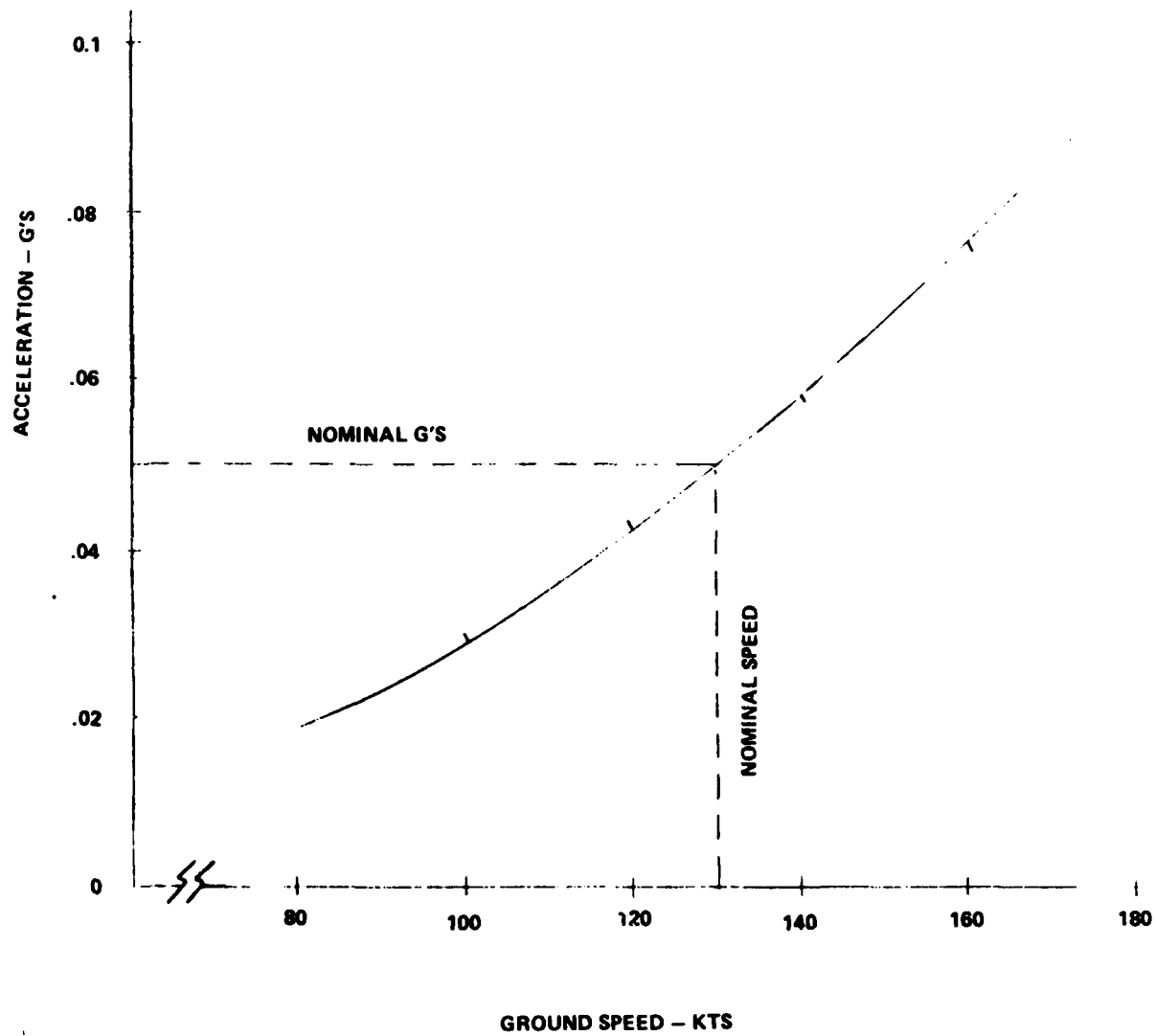


Figure 14 Variation of Normal Acceleration With Speed

3.1.3 Designation of MLS Waypoints

The MLS waypoints define the complex trajectory to the MLS computer. Two basic alternate methods of defining these waypoints were considered.

The first method, used in present-day RNAV systems, was also used in the USAF FPI Program. The waypoints were designated at the intersection of the straight line segments of the trajectory. Since the aircraft always flew along a circular arc connecting these segments it never actually flew through the waypoints.

These waypoints were used by the crew as progress checkpoints, and the data associated with them was the only data available to be used by the crew as a reasonableness check that the aircraft was accurately flying the desired track. However, since the aircraft never actually passed through the waypoints, the waypoint coordinates had very limited value from a monitoring viewpoint.

An alternate method of defining waypoint/progress check points, which circumvents this problem, is to define waypoints which are actually on the trajectory. These points may be at the transitions between the straight and circular track segments, or anywhere along these segments.

This alternate method appears to be most promising from a monitoring viewpoint and will be evaluated in the next phase of study. The detailed means by which trajectories are defined to the MLS computer, in this manner, is treated elsewhere in this report. It is of interest here, however, to demonstrate how the choice of designating waypoints affects the amount of data (and thus workload) which the pilot must enter into the CDU to define the trajectory to the MLS computer.

Let us examine a general trajectory such as depicted in Figure 15a. This trajectory is made up of the GPIIP two horizontal waypoints (1&3), and two vertical waypoints (2&4, assumed to be not coincident with the horizontal waypoints).

With the present T-39/MLS navigation program the crew member inserts, via the CDU; the inbound course to the first waypoint, the MLS azimuth, MLS horizontal range, and barometric altitude of each of the waypoints (including the touchdown point), and the runway course. In addition, he must insert the turn radius about WP1 and WP3 if they are different from a standard turn. Note that the present program is limited so that a vertical waypoint can not be located on a curved horizontal path.

The alternate means of specifying the same trajectory is depicted in Figure 15b. The horizontal trajectory is specified first by inserting the runway course and the range to the first circular arc transition (note that the trajectory is being specified starting at the GPIP). Next the arc radius and turn direction are inserted. This is followed by the course and range from the end of the first transition to the beginning of the second transition, the next radius and the turn direction, and finally the initial inbound course. Next the vertical trajectory is defined by the glide slope angle of the final leg, the along track distance (ATK) from the GPIP at which the glide slope transition is initiated, the previous glide-slope angle and the ATK at which it is initiated. Note that vertical transition points, whose location is now inserted via ATK, can now be situated on a curved path segment.

Let us now examine the difference in the number of data inputs required to define the track.

- 1) Present Method
 - 5 MLS Azimuths
 - 5 MLS Ranges
 - 5 Baro Altitudes
 - 2 Radii
 - 2 Courses
 - 19 Total

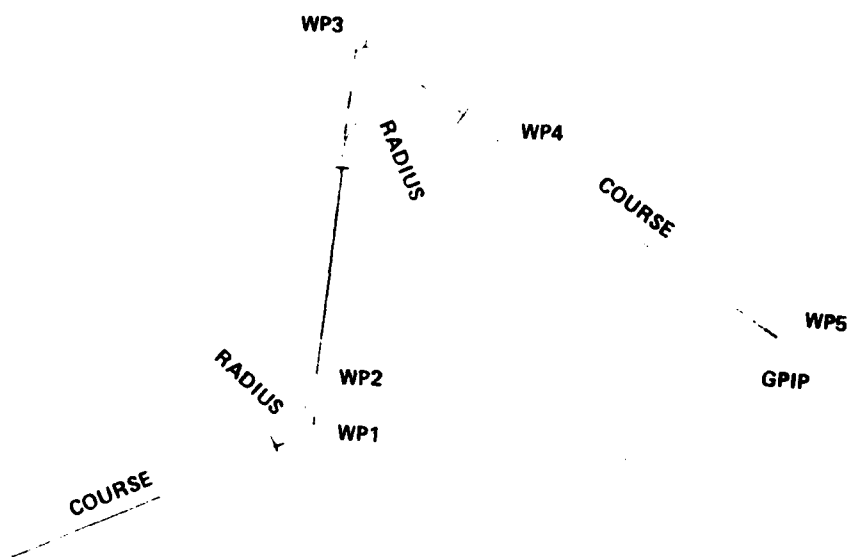


Figure 15a

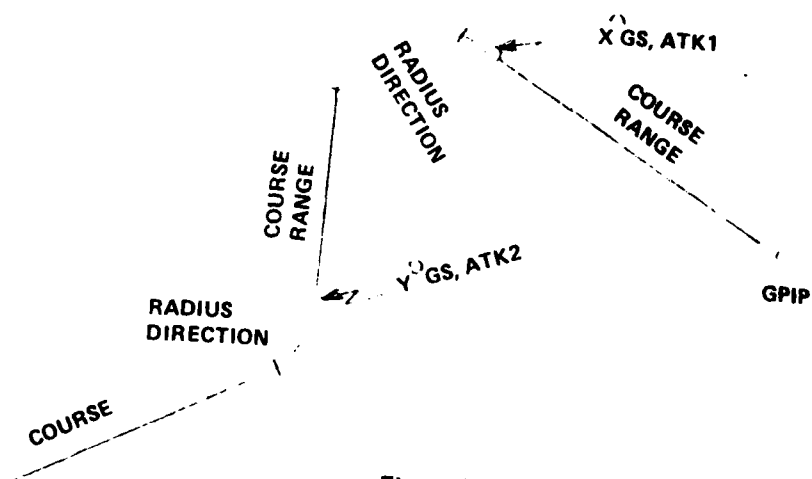


Figure 15b

Figure 15 Two Alternate Means Defining Trajectories

- 2) Alternate Method
 - 3 Courses
 - 2 Turn Directions
 - 2 Ranges
 - 2 Radii
 - 2 G.S. Angles
 - 2 ATK's
 - 13 Total

This is a significant decrease in data entry requirements and represents in itself a significant relief in pilot workload. In addition, the alternate method is specifying the trajectory in the same terms which the pilot normally thinks of his flight, e.g., left turn to 128 degrees, initiate let-down 6 miles from touchdown, etc.

3.1.4 Approach Plate Design

From a human factors viewpoint there is an obvious advantage to designing the MLS approach plate to appear in the same format as the familiar conventional charts published as Low Altitude Instrument Approach Procedures. To accommodate and facilitate MLS approaches, the following additions to these charts are recommended.

- 1) The waypoints/progress check points should be sequentially numbered and should be on the designated horizontal and vertical trajectories.
- 2) The data illustrated for these points should show the basic MLS azimuth, range, and elevation angle with respect to the MLS transmitters. (Barometric altitude may be used in place of MLS elevation angle).
- 3) Prescribed turn radii should be illustrated.
- 4) A table should be added, containing data in the format and sequence necessary to define the trajectory to the MLS computer.

The first requirement stems from the fact that the waypoints/progress checkpoints are used by the crew as a reasonableness check that the aircraft is flying the desired trajectory (for instance, the point of intersection of two linear segments which have been connected by a circular arc) has only limited value from this viewpoint.

The second requirement stems also from a monitoring consideration. In order to have a high degree of confidence in the validity of the trajectory being flown, it is desirable to check against the lowest level (least processing) of aircraft position data.

The third requirement results from the fact that the MLS computer, in a turn, will output its error information based upon the deviation of the aircraft from a prescribed circular track segment. The pilot must therefore fly this preselected circular track (as opposed to an arbitrary one of his choice), connecting the straight line segments, if he wishes his error display to remain nulled. In addition, it is obvious that since the trajectory may contain descending turns, any deviation from the prescribed horizontal turn trajectory would also require changes from the prescribed glide path angle in order to exit the turn at the required altitude.

The fourth requirement comes about from considerations of the pilot interface with the CDU for manual insertions of trajectory data. In general, the MLS trajectories are too complex to expect the pilot to simply extract the data and the sequence of data entry from the horizontal and vertical projections on the approach plate. Even for relatively simple trajectories, significant workload simplification result by tabulating the data to be loaded on a dedicated portion of the approach plate.

Note that the tabulated data need not have a direct correspondence to the data shown on other parts of the profile, and that the crew may not, necessarily, have a requirement to know the meaning of this data other than that it defines the trajectory to the MLS computer. Thus, many types of alpha-numeric coding techniques are possible with the final aim being to allow simple entry interface with the CDU and also to allow the MLS computer to check the validity of the data introduced.

On the other hand, it may be best to present this data in a format which makes apparent the meaning of each entry. The argument for this arrangement is that if the pilot knows the meaning of each data entry, he is less apt to enter it erroneously, e.g., if the pilot is to enter a course angle of 324 degrees he is less likely to enter

824 or 432 since he knows inherently that no such courses exist. Similarly, if he is to enter a vertical path angle of 3.2 degrees, he is less apt to enter 32 degrees. Thus, it may well be that the pilot workload of entering, checking, and correcting erroneously entered data (averaged over many flights) may be less if the format of the data entry is such as to allow a correlation between the data to be entered and the physical world. Even if more initial data entries are required, the average workload may decrease because less correction of errors is required.

Figure 16 illustrates an approach plate used in the USAF FPI Program. The MLS profile is displayed as a horizontal map and a vertical (unrolled) profile. Numbered waypoints are displayed on the horizontal map along with corresponding courses, MLS azimuths, and DME readings. The vertical profile displays the barometric altitudes, glide slope angles, distances between checkpoints and transition points, along track distances (referenced to the glide path intercept point) and the MLS elevation angles. Note that it is difficult, to obtain a spatial correspondence between the horizontal and vertical projections.

The table in the lower left corner contains, in tabulated form, the data necessary to define the profile to the MLS computer and other data which expresses the profile in different terms. The actual data, which was entered into the MLS computer via the CDU in order to define the trajectory, was the MLS azimuth angle, the range from the DME transmitter and the elevation (barometric attitude) of each of the waypoints. In addition, the inbound track angle to the first MLS waypoint and the runway course were also entered via the CDU. If waypoint 32 is considered as an MLS waypoint (it is just within MLS coverage), the total number of waypoints needed to describe this trajectory was six. Since three coordinates were entered for each waypoint in addition to the first inbound and runway courses, the total number of entries to the CDU was twenty.

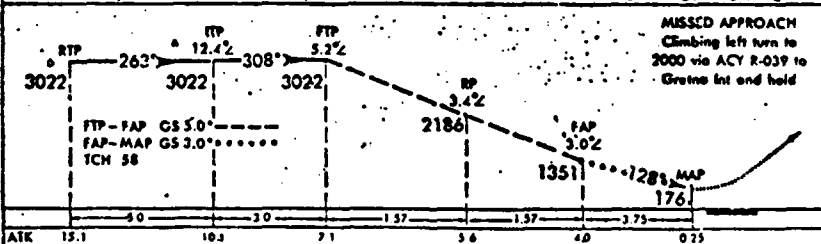
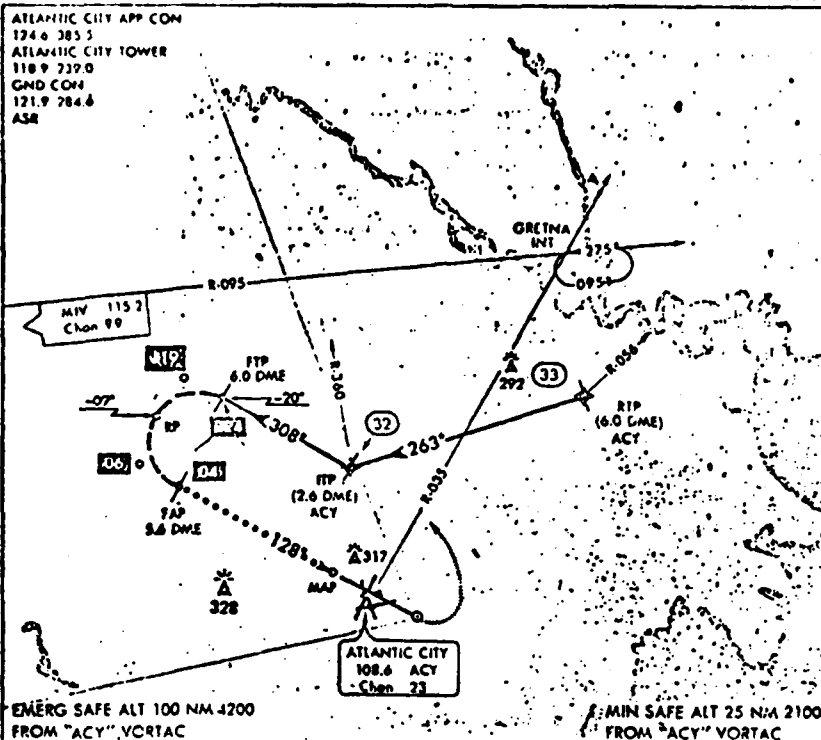
Figure 17 illustrates the same trajectory designated in a different manner. Waypoints are designated at vertical and horizontal transition points and numbered sequentially so that waypoint "zero" corresponds to the GPIP. These waypoint numbers appear on both the horizontal and vertical projections thereby facilitating the process of correlation

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118.9 239.0
GND CON
121.9 284.6
ASR



WPT	AZ	RANGE	ELEV	ITK	OTK	DPA	NPA
33	56.34	5.97	3022	263	263	00	00
32	00.01	2.70	3022	263	303	00	00
-24	-19.80	5.91	3022	308	218	00	-03
-19	-16.95	6.86	3022	308	218	00	-03
06	0.0	6.56	2186	218	128	-03	-03
04	0.0	5.56	1351	128	128	-03	-03
00	0.0	1.81	176	128	128	-03	-03
00	0.0	1.56	76	128	128	-03	00

EXPERIMENTAL PROFILE FOR IFC RD USE ONLY

Figure 16 FPI Approach Plate

MLS RWY 13-257

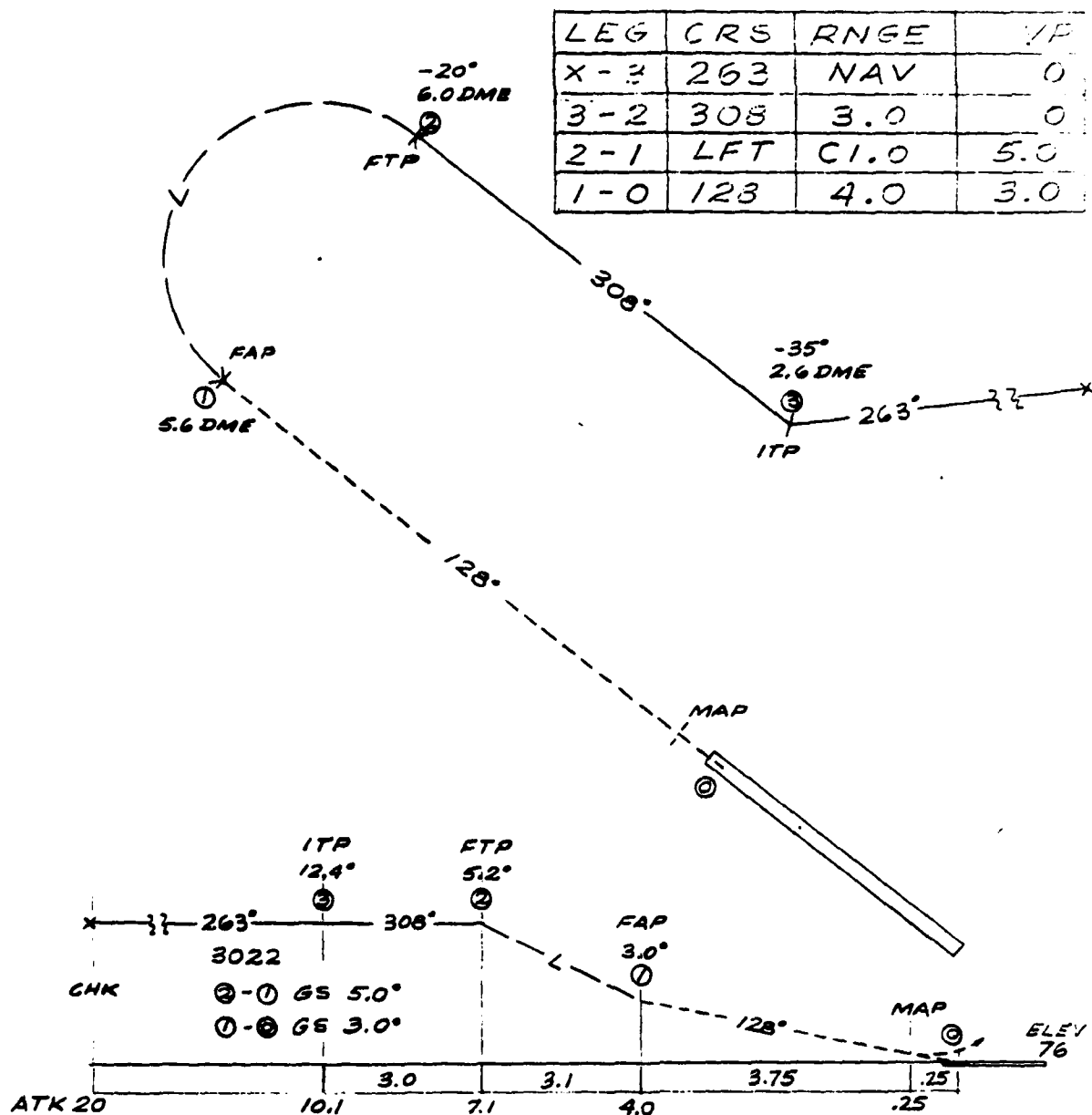


Figure 17 MLS RWY 13-257

between the projections. As shown in the tabulated data, the trajectory is now defined to the computer in terms of its segments (legs) rather than in terms of waypoints. Straight line segments are designated by their course, their length, and their vertical path angles. Circular arc segments are designated by their direction of turn (left or right), their radius (measured in the horizontal projection) and their vertical path angles. Note that for the example shown, the number of data entries via the CDU is now ten, half of the previous requirement (only the inbound course for the first leg is entered).

An alternative to the concept of separate horizontal and vertical profiles, and the correlation problems they present, is the integrated "3D" perspective approach plate illustrated in Figure 18. The characteristics of the trajectory in three-dimensional space are now much simpler to visualize.

All of the alpha-numeric data that was previously spread over the two projections must now be incorporated into one, and consequently there is some tendency for the illustration to appear obscure or cluttered. For the trajectories considered this did not prove to be a problem.

One additional problem that a "3D" perspective presents comes about because the remainder of the approach plate (e.g., topographical features) is not in 3D perspective. As a result, the trajectory projection on the horizontal plane appears distorted, in both shape and position, relative to the remainder of the features. To overcome this a "3D pseudo-perspective" approach plate was considered.

Figure 19 depicts such a pseudo-perspective plate. Note that now the trajectory projection on the horizontal plane is the same as in Figures 16 and 17. The shape, size, and position of the horizontal projection can now be consistent with the remainder of the horizontal map.

Figure 20 represents the finished product. A comparison with Figure 16 illustrates the significant improvement in visualizing and extracting pertinent data about the complex trajectory from the approach plate.

2	1	2	3	4
1-0	123	4.0	3.0	

Diagram details:

- Point 1: 0°A, 3.0°E, 5.6 DME, 4.0 FTP
- Point 2: -20°A, 5.2°E, 6.0 DME, 7.1 FTP
- Point 3: -35°A, 12.4°E, 2.6 DME, 10.1 ITP
- Point 4: 25 MAP
- Distances: 3.1, 3.0, 3.75, 2.25, 2.0
- Angles: 65 5.0°, 308°, 263°, 128°, 65 3.0°
- Labels: CHK, ATK, ELEV 76

47

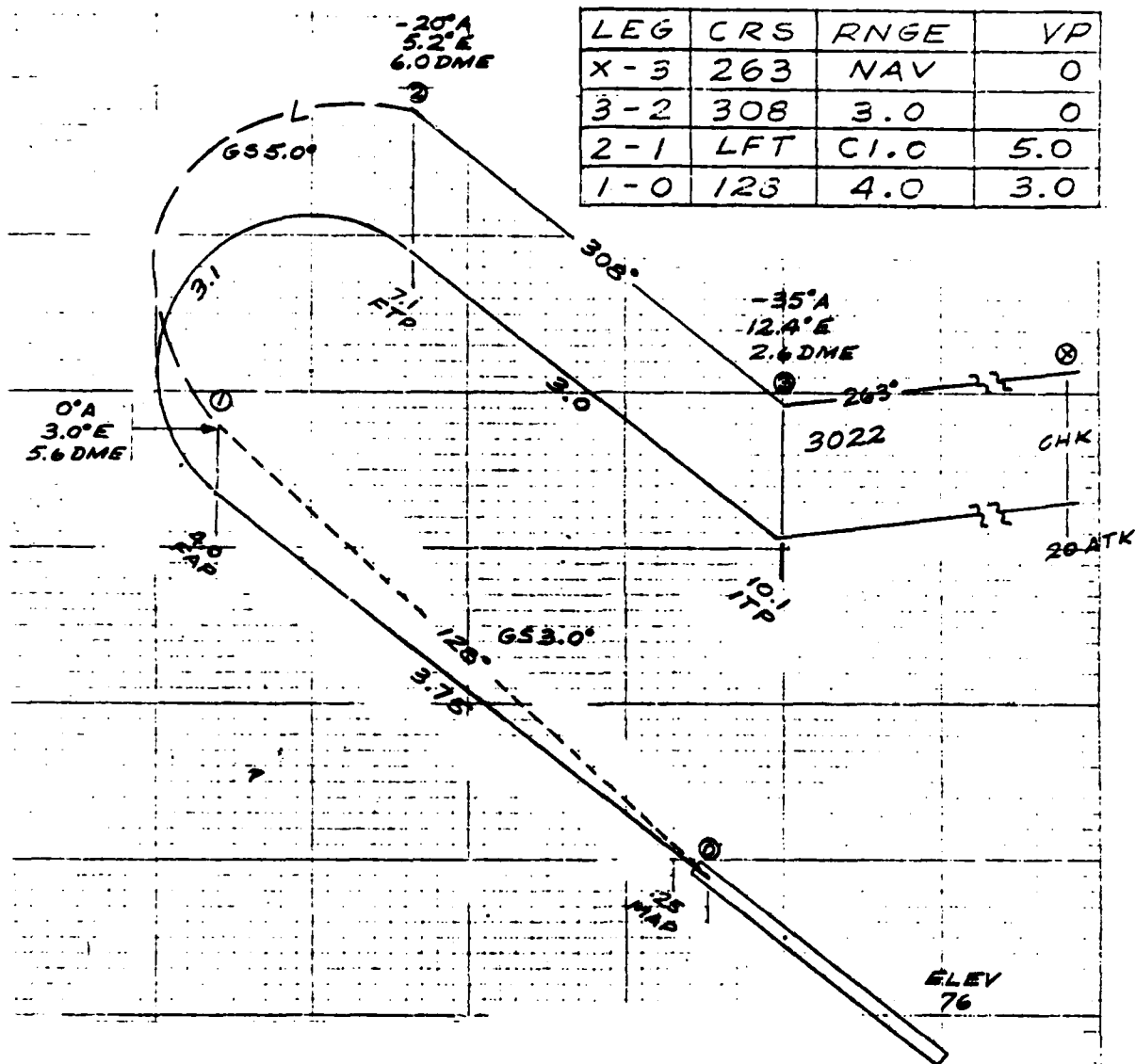


Figure 19 CDI "3-D Perspective"; -1 NM/Inch MLS RWY 13-257

An additional factor relative to the 3D approach plate requires consideration from a human factors viewpoint. It will not always be possible to maintain a "North-Up" orientation for the approach plate. If the straight line segments of a trajectory run north-south, the trajectory and its horizontal projection will be coincident. In fact, the value of the 3D projection is degraded if the segments run close to north-south.

It will therefore be necessary for the approach plate designer to rotate the trajectory into a position which results in maximum advantage of the 3D perspective. Figures 21, 22 and 23 illustrate the effectiveness of such a rotation in clarifying the 3D perspective. Figures 24 and 25 show two different versions of the same "teardrop" trajectory and demonstrate that the approach plate designer must be free to select the projection which most adequately depicts the trajectory. Clearly, the version of Figure 25 is far superior to that of Figure 24 which requires looking through the vertical "walls" to see the remainder of the trajectory.

3.1.5 Profile Commonality

It is expected that certain standard trajectories will be common to many aircraft and airports. In these instances, it will only be necessary to insert into the CDU the class or identifying numbers of the trajectory and a minimum of data which distinguishes this particular trajectory from all others in its class. This represents an enormous saving in workload contributed by the CDU interface.

Consider for example a trajectory which consists of a U-turn (trombone) in the horizontal plane and a constant glide slope in the vertical plane. Further assume that the U-turn is always composed of: a downwind flight parallel to, but offset, from the runway; a fixed radius 180 degree turn to the left terminating on runway heading at a fixed distance of 2 miles from touchdown; and, a constant 3 degree glide slope. Thus, the only variable in this class of U-turns is the runway heading; moreover, by inserting two numbers (the trajectory class and the runway heading) the trajectory is defined. Note that the approach plate would illustrate all details of this trajectory, but the tabulated data would contain only the information required to define it to the MLS computer.

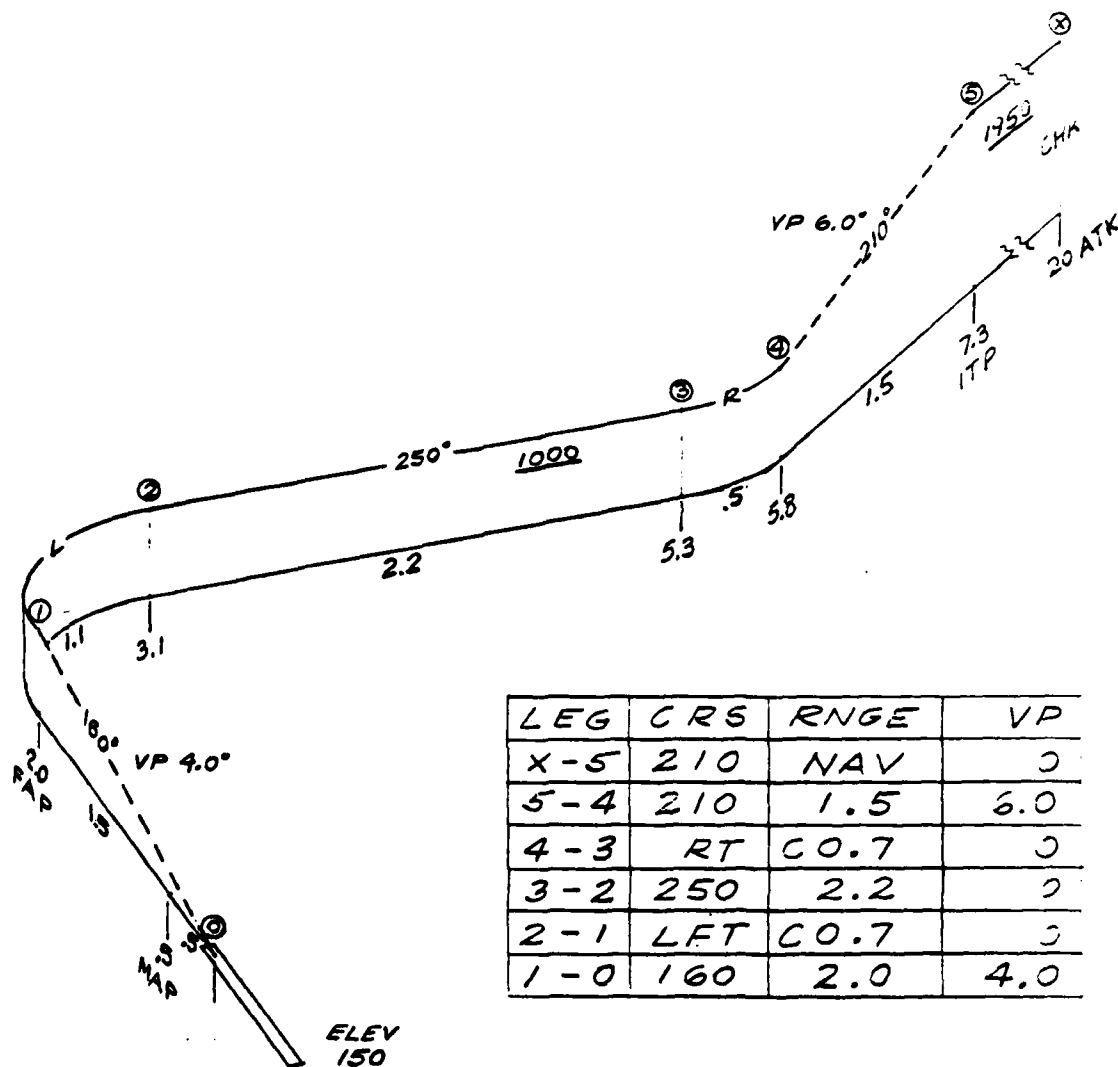


Figure 21 CDI 30° Perspective; 1.5"/NM MLS EWR 16L

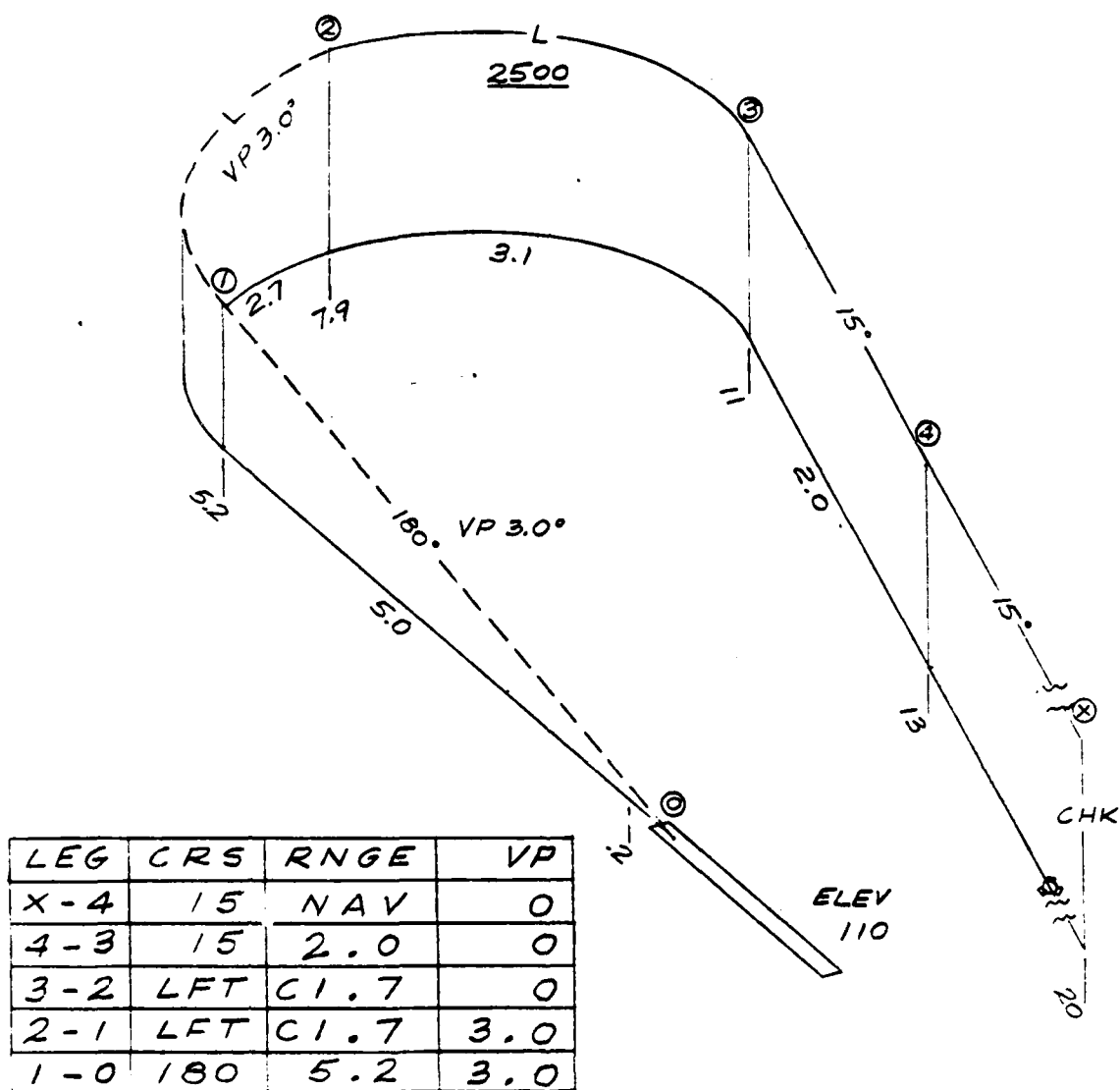
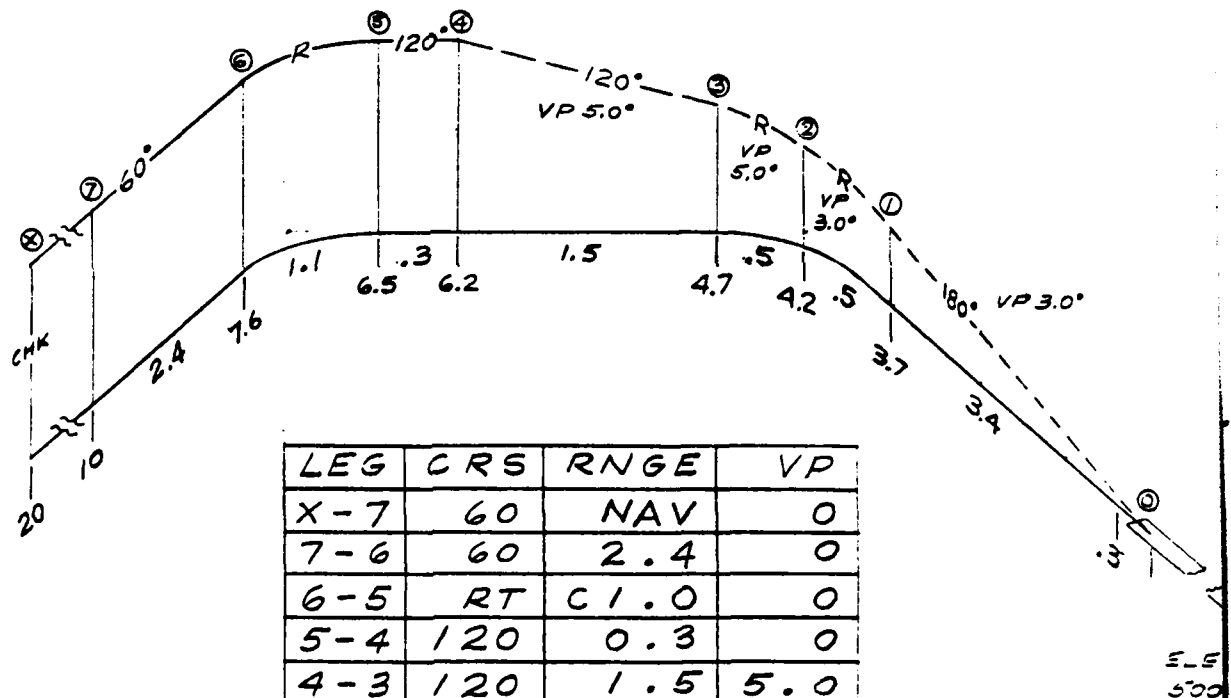


Figure 22 CDI MLS STL 18L



LEG	CRS	RNGE	VP
X-7	60	NAV	0
7-6	60	2.4	0
6-5	RT	C 1.0	0
5-4	120	0.3	0
4-3	120	1.5	5.0
3-2	RT	C 1.0	5.0
2-1	RT	C 1.0	3.0
1-0	180	3.7	3.0

Figure 23 CDI MLS STL 18R

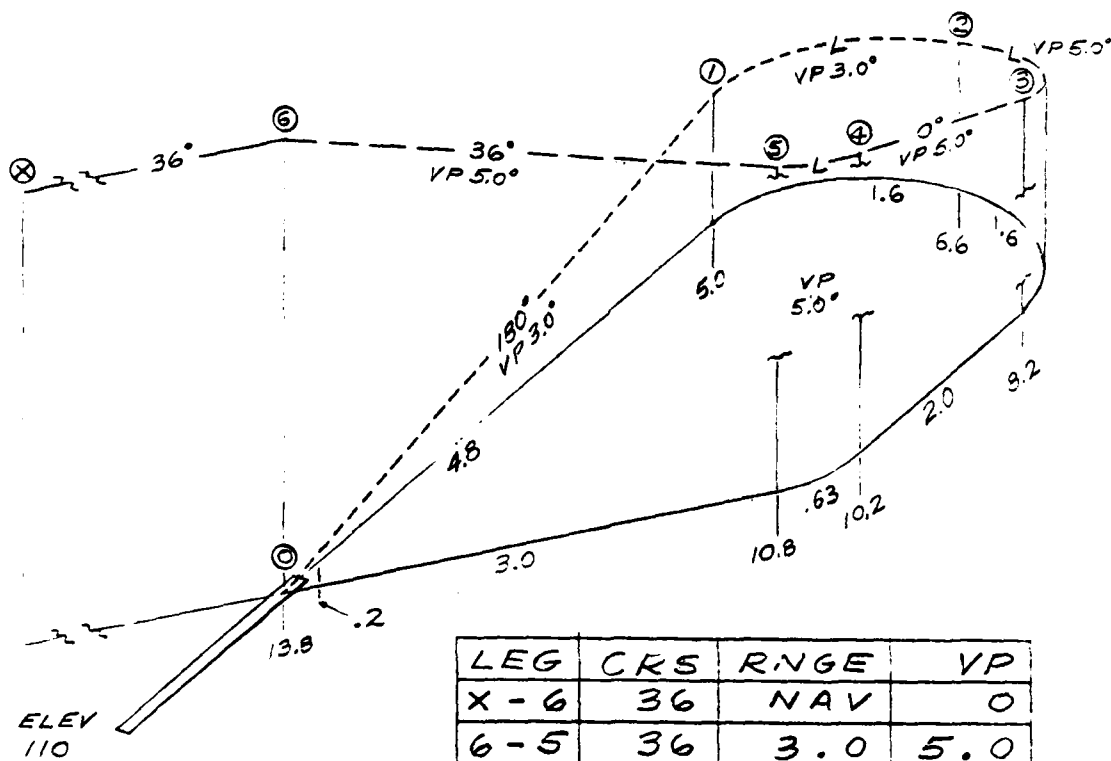


Figure 24 CDI MLS OAK 18L (Version 1)

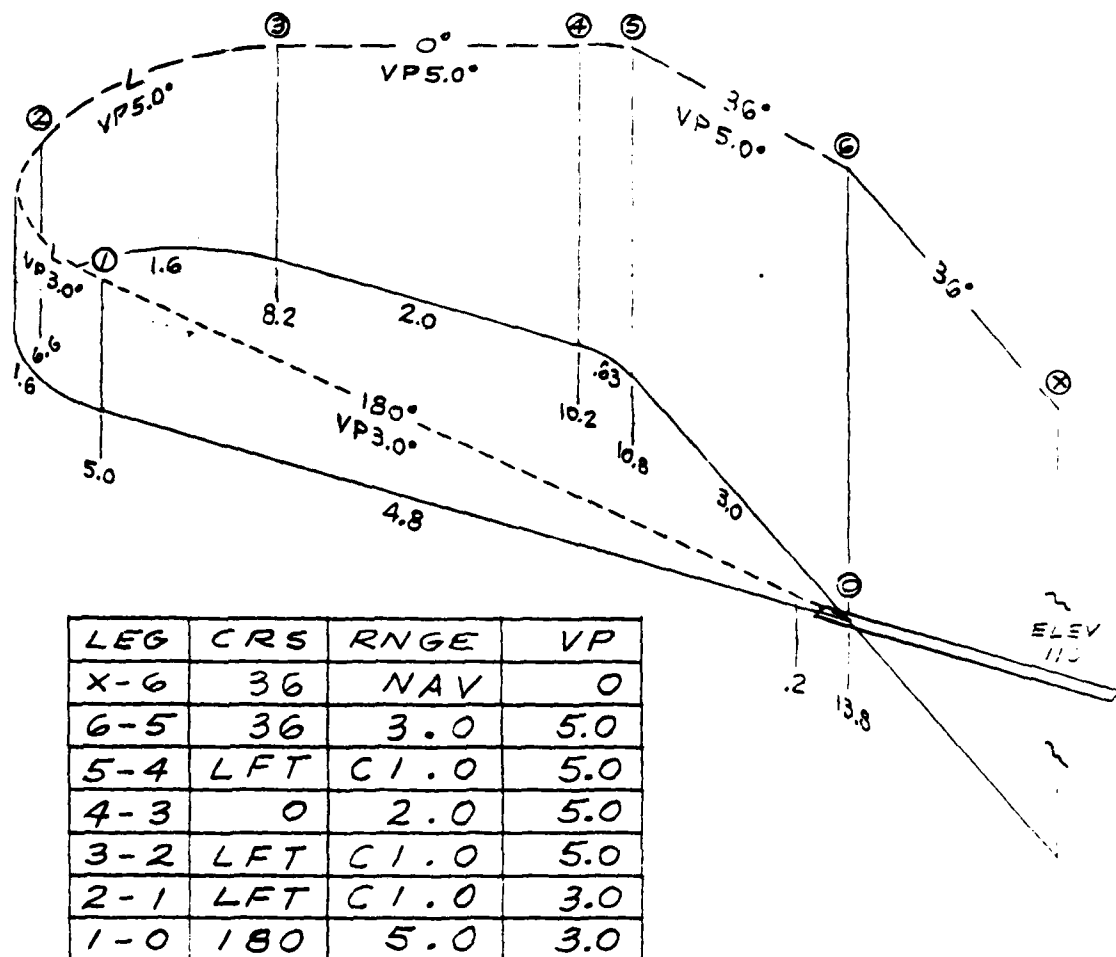


Figure 25 CDI MLS OAK 18L (Version 2)

It is anticipated that the great majority of MLS trajectories will eventually be classified into these standard type maneuvers. Fortunately, the MLS avionics development effort is still at the stage where the capability to accomodate these standard trajectories could be added to the specification. It is necessary that the civil/military agencies define these standards soon so that retrofit of the avionics can be avoided.

If a significant percentage of MLS trajectories can be classified into a small number of standard trajectories, it will impact other facets of MLS requirements and tradeoffs (i.e., CDU design and interface considerations, means of cross-checking data entry, automatic vs. manual profile insertion and approach plate design).

3.2 Complex Trajectory Monitoring and Redundancy Requirements

3.2.1 General Considerations

With the advent of MLS, aircraft will be capable of making precision approaches which are not confined to the conventional ILS "straight-in" types. Virtually all combinations of trajectories composed of circular arcs and straight line segments will be possible both in the horizontal and vertical planes. The value of these complex trajectories lies primarily in their ability to contribute to a higher recovery rate, obstacle avoidance, noise abatement, and to avoid overflying enemy territory. If MLS trajectories are defined and used to achieve this greater capability, a corresponding danger will, in some instances, accompany their use. For instance, if the trajectory is used for obstacle avoidance, an undetected malfunction carries with it connotations of extreme danger.

There is an analogy to this situation in flying ILS approaches under IFR conditions. When Category I, II, and III approaches were made possible by more accurate and sophisticated equipment, the danger of the proximity of the ground had to be addressed. This resulted in the FAA requirements dealing with monitored, fail-passive and fail-operational equipment. The final requirements took many years to formulate since the capabilities of the human pilot to monitor and react to failures could only be assessed over

a multitude of real landings. A similar situation now exists with regard to flying complex trajectories which are critical from the viewpoint of the proximity of obstacles, enemy fire, on other aircraft.

It is the purpose of this section to make a start in the direction of defining the monitoring and redundancy requirements for complex MLS trajectories. Wherever applicable, information gleaned from the USAF FPI Program and from ILS IFR approaches are used. The reader will note that the conclusions are conservative. That is, more complexity is proposed until it can be proven that simpler systems are safe.

3.2.2 The Pilot As a Monitor During Complex Trajectory Flight

The typical MLS complex trajectory may consist of two or three straight line segments, connected by two or three different flight path angles in the vertical plane. The flight path angle changes may occur during the turns.

The FPI program has demonstrated that if the aircraft is under manual control, the workload associated with flying these trajectories precludes monitoring to determine whether the trajectory being flown is the trajectory desired. This is not to say that gross errors can not be detected. For instance, the pilot can detect that he is being asked to turn in the wrong direction or that the bank angle required to fly the turn is much too large, or that his descent rate has been too high for too long, etc.

The detection of even these gross errors is not easily accomplished because in order to determine the reasonableness of a particular maneuver at a particular time, the pilot must know where he is in progress along the trajectory. The only means he has to determine his progress (with present displays) is a digital readout of his upcoming waypoint which he must correlate with his approach plate, forcing his attention away from his control/display. He may also rely upon his memory of what the approach plate looked like, but he cannot be expected to memorize the characteristics of a complex trajectory.

If the aircraft is under automatic control, the pilot

has considerably more time for monitoring. He may refer to the approach plate more easily to determine the reasonableness of the trajectory he is flying, and can more easily detect gross errors and monitor his progress along the trajectory. He can not, however, monitor accurately his position with respect to the runway or with respect to the approach plate trajectory. This is not meant to imply that he can not monitor his position relative to the trajectory to which he is being controlled. The difficulty comes about when due to a fault, that trajectory is different from the approach plate trajectory, or when the error from the trajectory is being computed erroneously.

In order to detect these subtle types of faults he must have an independent reference to monitor against. If we assume that the transmitters and receivers are adequately self-monitored, then the faults which are of concern are: those of the MLS computer which performs the error computation for display; and, the control/display itself.

These types of faults could be detected by comparing the raw data output of the receiver to known coordinates of the approach plate. This is equivalent to the type of monitoring performed by the pilot during an ILS approach when he utilizes raw localizer and glide slope deviation signals from the receivers.

The raw data output from the MLS receivers are azimuth angle, elevation angle, and slant range. That is, they are in polar coordinates. When flying a complex trajectory, or any path which is not a straight line pointing directly at the azimuth and elevation transmitters; these coordinates are constantly changing, and their significance is also changing. For instance, when flying a path which is perpendicular to (or makes a large angle to) the runway course, the aircraft's lateral deviation from the path is a function primarily of range error and elevation angle. When flying at a shallow angle to the runway course, lateral deviation is a function primarily of azimuth angle error and range.

Thus, even if the pilot knew the MLS coordinates of every point on the approach plate trajectory and the raw data corresponding to his present position, it would be difficult to assess quantitatively his errors from the desired path. Furthermore, and equally important, he cannot distinguish

between being on the trajectory but not at the progress point he believes, and being off the trajectory. In addition because the raw data is constantly changing with time (unlike the straight-in ILS approach where the azimuth and elevation angles are fixed) the pilot must constantly "chase" the raw data to assure that a failure has not occurred since his last check.

3.2.3 Recommended Design Criteria To Enable Pilot Monitoring of Complex Trajectories

It is recommended that the following equipment be evaluated in further studies for the purpose of determining their value as aids to pilot monitoring of complex trajectory flight.

- 1) A means whereby the pilot may quickly and easily determine that the data he entered to define the complex trajectory was entered fault free.
- 2) An electronic display which pictorially illustrates the complete horizontal and vertical trajectories and the aircrafts progress along them.
- 3) A digital display driven by the MLS receivers (independent of the MLS computer) which allows the direct readout of basic azimuth angle, elevation angle and range. Means should be provided to "freeze" the displayed data either by pilot action or by the MLS computer. The data shall "unfreeze" automatically after TBD seconds.
- 4) Printed raw data coordinates at strategic points along the trajectories, illustrated on the approach plate.

It is expected that the above functions will give the pilot the capability of checking raw data at known progress points against those on the approach plate. It remains to be determined whether he has sufficient time to do so, in manual and automatic flight, and whether he can relate this data to path deviation data well enough to distinguish between expected deviations during normal flight and

deviations caused by faults.

3.2.4 The Pilot As a Monitor on the Final Approach Leg

On the final approach leg, the trajectory will be a fixed course and descent angle. In addition to his manual control/display and/or his automatic landing system, the pilot will have available to him raw data indicating angular deviations from both the selected azimuth and elevation angles and distance to touchdown.

Aside from the addition of range information, this is the same raw data format presented to him during present day ILS approaches. It is therefore safe to assume that the pilot's ability to monitor will have the same characteristics as presently exhibited during ILS approaches.

3.2.5 Missed Approaches

A missed approach may have to be executed due to detected malfunctions or other crew emergencies. On the final approach leg, a missed ILS approach is executed by overflying the missed approach zone where obstacles are nonexistent (or controlled) and from where the pilot knows the predetermined missed approach profile.

On the final approach leg, the MLS missed approach will be flown in the same manner. However, an aborted landing initiated during complex trajectory flight may present a different type of problem. The potential severity of the problem depends on why the aircraft is flying a complex trajectory. If the path is being flown, for instance, to avoid obstacles under IFR conditions, an aborted approach obviously carries with it the danger of impacting these obstacles. Flying up or leveling out is, of course, the correct and natural thing to do, but since the aircraft may be below the height of nearby obstacles its horizontal path is equally important.

In the general case of general trajectories and arbitrary obstacle locations, the pilot is expected to find it very difficult to safely abort from his complex trajectory flight. To do so, he must know his position and direction of flight just prior to abort, refer to his approach plate which shows the location and height of those obstacles;

decide upon a flight path which will avoid those obstacles; and then, with no ground based reference system to assist him, fly out of his dangerous situation.

It is suggested here that the safest procedure may be to continue flight onto the final leg to the runway (from where the abort procedure is safe and well defined) and execute his normal missed approach procedure. However it is doubtful that he can accomplish this safely without the MLS system or an equivalent ground based reference system.

We must therefore draw the conclusion that for some intended uses of MLS it is insufficient from a safety viewpoint merely to know that a failure exists. It would also be necessary to have a means of continuing accurate flight to at least the final leg (or to landing) in the presence of that failure, that is, the system must be fail-operative.

Note that this requirement is independent of whether the aircraft is equipped to perform Category I, II, or III landings. These categories are associated with visual range in the vicinity of the touchdown point on the runway. The fail-operative requirement stems from visibility considerations in the vicinity of higher altitude obstacles.

3.2.6 Recommended Monitoring and Redundancy Requirements For MLS Avionics Equipment

The specification of monitoring and redundancy requirements for MLS airborne equipment is premature from the viewpoint that these requirements must stem from an assessment of pilot capability to control and monitor complex trajectory flight. This assessment is not yet complete; however, for the purpose of initiating a dialogue on this subject and to demonstrate the hardware repercussions associated with various pilot capabilities, the following alternatives are proposed.

In all instances it is proposed that the MLS computer(s) will directly drive the controls/displays and furnish steering commands to the automatic flight control system(s) during the complex portions of the trajectory. After initiation of the final straight-in approach leg, control will revert to the automatic flight control system(s)

and the flight director computer(s) which will drive the control/display(s). These systems will receive raw deviation data directly from the MLS receiver(s).

Thus, the monitoring and redundancy requirements fall into two distinct categories - requirements before the final leg during complex trajectory flight, and requirements during the final approach leg.

The latter requirements are expected to be similar to those specified by FAA Advisory Circular 120-29, dated 9/25/70 (with attachments and revisions) for Category I and Category II landings and Advisory Circular 120-28B, dated 12/1/77 for Category IIIa landings.

During complex trajectory flight, if we assume that the pilot can both adequately manually fly and detect faults (other than received faults) and that he can adequately execute a missed approach anywhere along the trajectory without MLS data, the avionics requirements would be:

- a) A single self-monitored receiver
- b) A single independent raw data display
- c) A single MLS computer
- d) A single control/display or
A single autopilot

If he can adequately fly but not simultaneously monitor, the requirements would be:

- a) A single self-monitored receiver
- b) A monitored MLS computer
- c) A monitored control/display or
A monitored autopilot

If, he can not adequately execute a missed approach, the requirements would be:

- a) Dual self-monitored receivers

b) Dual monitored MLS computers

c) Dual monitored control/displays or
Dual monitored autopilots or
A monitored autopilot and a monitored display.

3.3 Complex Trajectory Display Information Requirements

3.3.1 General Display Information Criteria

In order to safely fly complex trajectory paths in the lateral and vertical axes using MLS, the pilot requires a significant amount of information. This information must be sufficient for:

- Controlling the aircraft about the desired path
- Monitoring aircraft systems' operation and performance
- Maintaining orientation with respect to the path and the runway

Moreover, the required display parameters must be formatted in an integrated cockpit presentation to result in acceptable pilot workload. Where workload increases beyond acceptable levels, automation and/or better display integration is required.

Although the display parameters to be utilized on a specific aircraft can only be determined by an analysis of the aircraft's existing systems' configurations and the desired level of MLS complex trajectory capability, a generalized set of MLS derived display parameters can be defined. Once defined, the specific aircraft's display parameters can be selected from the general list as compromises are made in conducting a cost-effective retrofit program.

In general, the display presentation technique can be quite different when standard electro-mechanical indicators and electronic CRT-type displays are considered. Much more capability is available when using a programmable display (e.g., the Bendix three-color CRT which is to be used in the simulator phase of this program). This capability should result in a more easily interpretable pictorial representation of the display information. Since most present-day USAF aircraft

either do not have programmable CRT's at all, or only use them as part of a weapons delivery system, the display information discussions in this section are primarily tailored to those aircraft with a standard ADI and HSI. The general information requirements, however, are also applicable to the electronic CRT's.

3.3.2 Complex Trajectory Display Parameters

Table 3 contains a listing of present displays used for basic aircraft control and navigation in the non-MLS environment. For complex trajectory flight, the control and performance display parameters shown are used intact and maintain their importance. The command and navigation displays are also used, as in ILS or TACAN, but in this case are driven from MLS computations. When MLS is used as a direct replacement system for ILS and only straight-in approaches are required, the display information shown in the table is sufficient for safe flight. When MLS, however, is used in flying complex trajectories, the display information shown is insufficient.

Table 4 contains a listing of possible MLS derived display parameters. The parameters have been divided into MLS receiver and MLS computer outputs. A discussion on each parameter follows.

Table 3 Present Aircraft Displays

<u>COMMAND</u>	<u>CONTROL</u>	<u>PERFORMANCE</u>	<u>NAVIGATION</u>
PITCH STEERING BAR	ATTITUDE	AIRSPPEED	BEARING
ROLL STEERING BAR	POWER	ALTITUDE	COURSE DEVIATION (CDI)
		HEADING	GLIDE SLOPE DEVIATION (GSI)
		VERTICAL VELOCITY	DME
		ANGLE OF ATTACK	TO-FROM

Table 4 MLS Derived Display Parameters

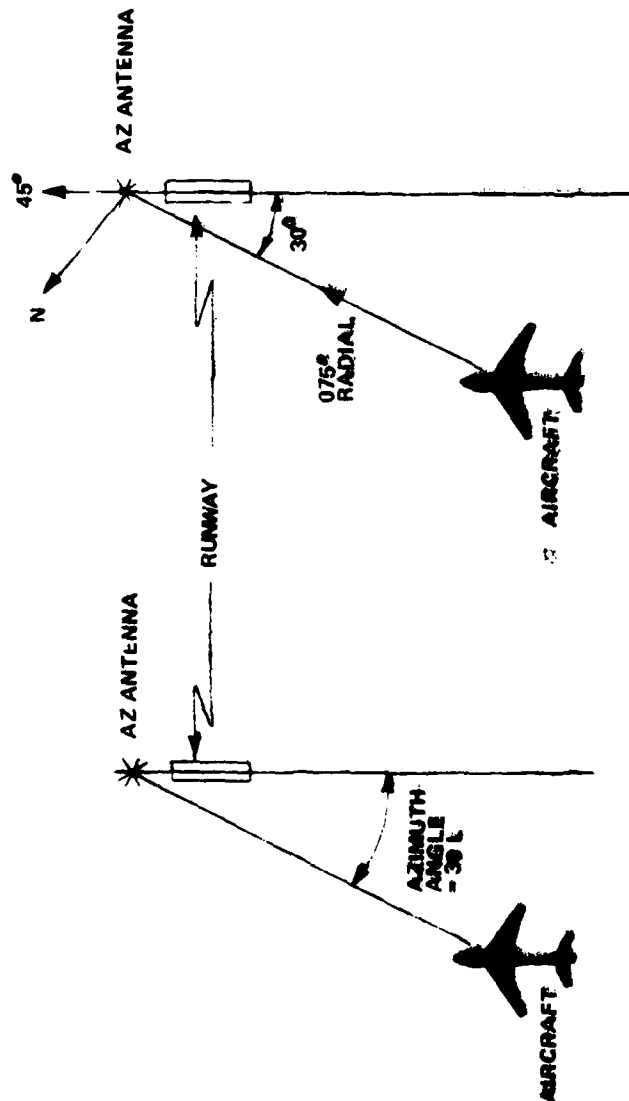
<u>MLS RECEIVER</u>	<u>MLS COMPUTER</u>
*AZIMUTH ANGLE	*DESIRED TRACK ANGLE
ELEVATION ANGLE	*LATERAL DEVIATION
RANGE-TO-STATION	*VERTICAL DEVIATION
*RANGE-TO-GPIP	RANGE-TO-WAYPOINT
RANGE RATE	*RANGE-ALONG-TRACK-TO-TOUCHDOWN
HEIGHT ABOVE RUNWAY	BEARING-TO-WAYPOINT
VERTICAL VELOCITY	*BEARING-TO-STATION
*LATERAL DEVIATION	FLIGHT PATH ANGLE
*VERTICAL DEVIATION	*PATH ANTICIPATOR
	AIRCRAFT POSITION PREDICTOR
	GROUND SPEED
	WIND SPEED AND DIRECTION
	EST. TIME TO GO TO:
	● WAYPOINT
	● TOUCHDOWN

*Recommended for display in existing USAF aircraft

MLS Receiver Outputs: As presently configured for the FAA Phase III MLS, the angle receiver outputs the aircraft's azimuth angle and elevation angle in the conical coordinate system in a digital format. It also outputs lateral and vertical deviation from the selected azimuth and glide slope angle, respectively, in an analog format. The MLS DME receiver outputs aircraft range information in the form of slant range distance to the site or the GPIP, range rate and height above the runway's altitude.

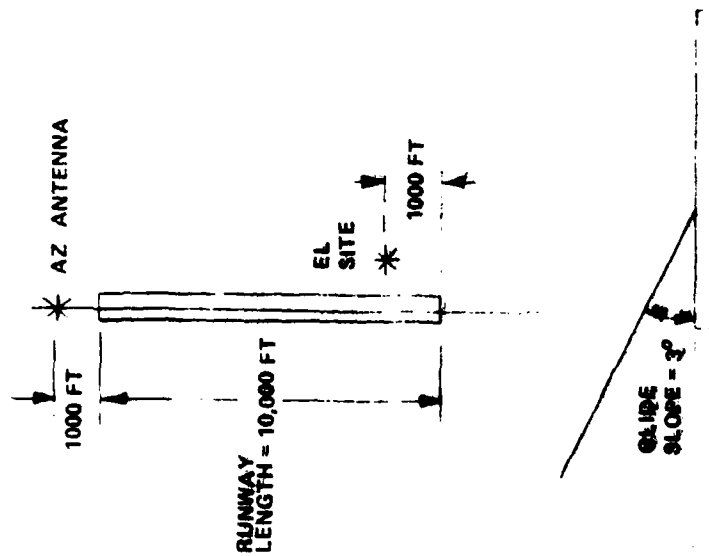
Azimuth Angle is defined as the angle between the runway centerline and the line connecting the azimuth ground site with the aircraft (see Figure 26a). A full capability MLS ground facility will provide azimuth coverage of ± 60 degrees about the runway centerline for a distance of at least 20 nautical miles. The present Phase III MLS airborne system provides a digital readout of azimuth angle in 1 degree increments, with the runway heading defined as 0 degree azimuth. With the aircraft 30 degrees to the left of the centerline, the display reads 30L.

From human factor considerations it may be better to relate



AZIMUTH ANGLE RELATIVE
TO RUNWAY
Figure 28a

AZIMUTH ANGLE RELATIVE
TO MAGNETIC NORTH
Figure 28b



TYPICAL MLS SITE GEOMETRY
Figure 28c

Figure 28 Azimuth Angle Geometry

aircraft azimuth angle to radial information with respect to magnetic north (see Figure 26b). The pilot's interpretation process of his situation will then be similar to that which he experiences presently with VOR and TACAN nav aids. It will also tend to make his transition from enroute navigation to INS terminal navigation simpler. The radial computation can be easily done within the MLS angle receiver because runway heading is one of the auxiliary data parameters which will be transmitted from the ground. By adding or subtracting azimuth angle from the runway heading, the aircraft's present radial to the ground site can be calculated and displayed. Since an "L" (for left) or "R" (for right) is required with a two-digit number to define the aircraft's azimuth angle, displaying 0 to 360 degree radial information does not result in a large increase in additional numeric readout hardware. This concept requires further study in a simulator or flight test program.

It is recommended that a digital readout of azimuth angle be displayed for MLS complex trajectory flight. Because the parameter is raw data direct from the MLS receiver, it can be used for crosscheck of computed commands and data for the aircraft with sophisticated complex trajectory capability. For the aircraft with less sophisticated computational capability or no automatic approach capability, it can be used as an aid in providing anticipation for close-in captures of straight-in ILS-type approaches not presently possible due to the coverage limitations of the ILS.

If a digital display of azimuth is provided, several areas must be considered in determining the resolution of the readout. If the display's primary function is to cross-check aircraft position during the complex portion of the approach, the resolution of 1 degree found on the present instrument is more than adequate. If, however, the display is also intended as an accurate final approach monitor of position, a greater resolution of 0.2 degrees or 0.5 degrees is required. The need for greater resolution during the final approach becomes apparent when a 0.5 degree azimuth angle (this is where the display would switch to 1L or 1R) is analyzed in terms of deviation in feet from the runway centerline. With the runway geometry shown in Figure 26c a 0.5 degree error in azimuth angle results in a 105 ft. deviation at 100 ft. of altitude. This is well outside the Category II (75 ft.) and Category III (27 ft.) 2-sigma

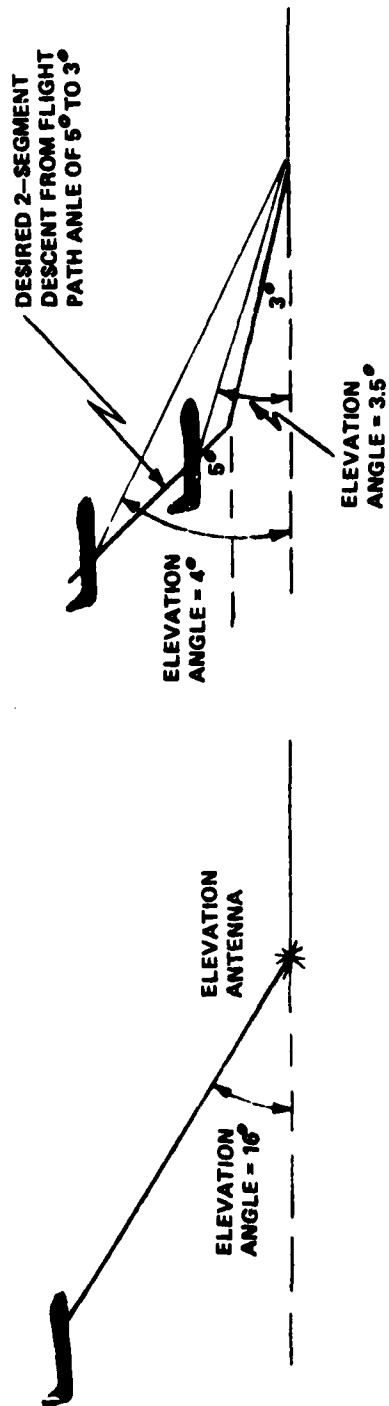
deviation windows. A resolution of 0.2 degrees (0.1 degree error causes change in readout) corresponds to 21 ft. and 0.5 degrees (.25 degree error causes change in readout) to 52 ft. In terms of human factors, if the digital readout is to be used for final approach monitoring, it would probably be better to have the pilot viewing deviation from null (i.e., about 0 degrees AZ) rather than with respect to a radial. In other words it is easier to interpret a display of 0.5 L as an error rather than displaying 275.5 and having the pilot mentally relate to the runway heading in deriving his angular deviation.

At this point in time, without the aid of further studies on the subject, it is recommended that azimuth angle be displayed as presently done in the Phase III system (i.e., about a 0 degree runway centerline reference with a resolution of 1 degree). The digital display should be used a gross indication of position and should not be primary for monitoring on the final approach segment.

Elevation Angle is defined as the angle between the extended runway centerline ground level and the aircraft (see Figure 27a.).

A full capability MLS ground facility will provide elevation coverage from 1 degree to 15 degrees above the ground level. The present Phase III MLS airborne system does not provide a display of this parameter; however, a display is provided in the MLS configured USAF T-39. Although the parameter is easily used for crosscheck of aircraft position in the vertical axis on the final approach leg where its value should remain constant (equal to the desired glide slope), elevation angle cannot be easily used during the initial segment of a two-segment descent because it is constantly changing (see Figure 27b).

With present ILS systems, the pilot monitors deviation from the glide slope on his glide slope pointer during the final approach. He will also have this information with MLS thus making a display of elevation angle redundant for this portion of the approach. Since elevation angle is difficult to use during complex approach segments, reliance on altitude appears to be the best solution. For these reasons, no display of elevation angle is contemplated.



ELEVATION / FLIGHT PATH ANGLE
RELATIONSHIP FOR 2-SEGMENT DESCENT

Figure 27b

ELEVATION ANGLE

Figure 27a

Figure 27 Elevation Angle Geometry

Range-to-GPIP/Range-to-Station are defined as the slant range distances from the aircraft to the respective reference point on the ground (see Figure 28a). The "glide path intercept point (GPIP)" is defined as the intersection point of the runway centerline and the plane, passing through the phase center of the elevation antenna, at an angle to the ground of the selected final approach glide slope (see Figure 28b). The MLS DME receiver has the capability of supplying either signal to the aircraft control-and-display systems.

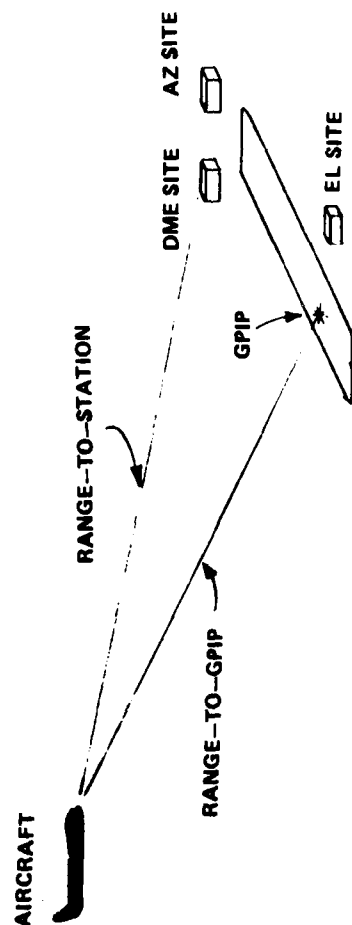
From a pilot's informational viewpoint, the desired reference for DME changes as a function of the phase of MLS flight. At all times, except after touchdown, the best reference point appears to be the GPIP since it relates the pilot directly to the runway touchdown zone. During ground rollout the best reference would be the DME ground site or, preferably, the end of the runway. In the Phase III MLS system this capability is provided in the form of an option whereby, if exercised, the reference is switched at touchdown as a function of landing gear compression. This, however, results in a discontinuity in displayed information and possible pilot confusion. If the option is not exercised in the Phase III system, the DME information presently displayed on the MLS DME indicator is flagged as the aircraft passes the GPIP. This is also undesirable since significant information is lost during a critical portion of the flight; moreover, the flagged indication might be disconcerting.

As a means of eliminating unwanted confusion and maintaining available information, it is suggested that distance to the GPIP always be displayed. That is, the signal should be computed within the MLS DME receiver as:

Range-to-GPIP= Absolute Value of (Range- to -
Station minus Distance from DME
Site to GPIP*)

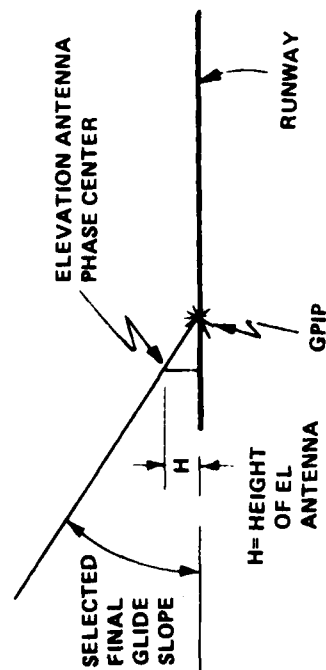
*obtained from auxiliary data information transmitted from ground

On final approach and landing, the signal will be steadily decreasing toward zero. At the GPIP and beyond, the signal will go to zero and then steadily increase during touchdown and ground rollout. From this an indication of distance



RANGE-TO-GPIP/STATION

Figure 28a



GLIDE PATH INTERCEPT POINT

Figure 28b

Figure 28 Range And Glide Path Intercept Point

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CONTROL-DISPLAY INVESTIGATION OF COMPLEX TRAJECTORY FLIGHT USIN--ETC(1

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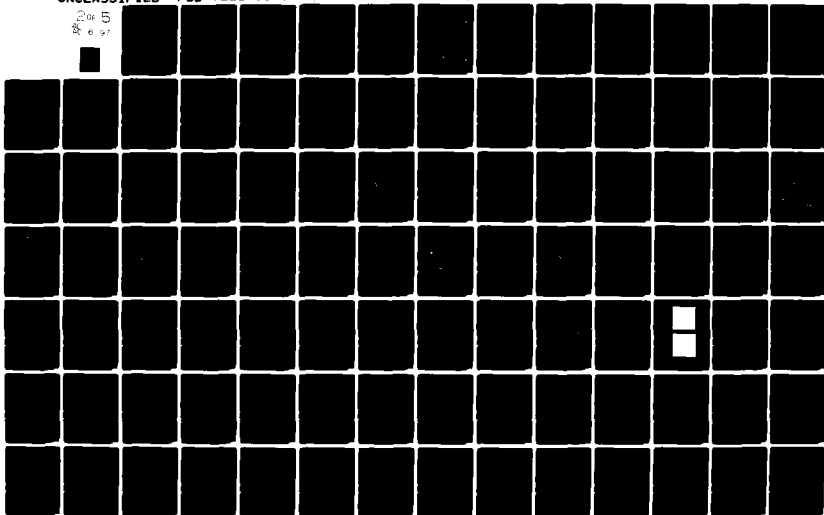
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to the end of the runway can be mentally computed if runway distance markers are not visible due to weather. To further clarify the aircraft's situation the TO-FROM indicator could be used during MLS flight and switched at the GPIIP. This, however, is not felt to be necessary.

It is recommended that a digital readout of range-to-GPIIP be displayed for MLS complex trajectory flight. Because the parameter is raw MLS data, like azimuth angle, it can be used for crosscheck of computed commands and computed data. It also becomes a replacement for marker beacon information during straight-in ILS-type approaches. Assuming a 3 degree final glide path angle, the displayed DME distance is directly relatable to desired altitude in that each nautical mile of DME is equivalent to approximately 300 feet above the runway elevation. This simple relationship would not exist if the DME was referenced to the DME site.

It is recommended that the resolution of the digital display be 0.1 nautical miles in the air. This will enable sufficient crosscheck capability to detect many errors with respect to the desired path and also will provide sufficiently resolved situation information with respect to the runway.

Range Rate is computed within the MLS DME receiver by differentiating the range signal. Although this parameter provides a reasonable indication of ground speed when the aircraft is heading directly at the DME transmitter (e.g., during the final approach or when flying along an azimuth radial) its use for CTOL and STOL aircraft is otherwise limited.

Primary use of this function is made by VTOL aircraft during hover and approach operations.

Height Above Runway elevation is computed within the Phase III MLS DME receiver by multiplying the range-to-GPIIP by the sine of the approach elevation angle. Because azimuth angle is not taken into consideration in the computation of range-to-GPIIP, the signal is accurate only along the 0 degree azimuth angle. If the accuracy is sufficient, this parameter can be very useful during the initial portion of automatic flare control due to its terrain-independent qualities. It does not, however, eliminate the need for a radio altimeter

because the signal is lost when the aircraft passes the elevation site.

Since most USAF aircraft do not have automatic landing modes and since, for those that do, use of this signal would involve a significant modification to the flare control law: use and/or display of this parameter is not recommended.

If this height is calculated using the flare elevation angle (instead of the approach elevation angle) and the corresponding DME range, it does become a direct replacement for the radio altimeter with the advantage of being terrain independent. Since the signal would be available throughout the landing maneuver, it would provide significant improvements to automatic flare control without modification to existing control laws.

Vertical Velocity is not presently computed in the Phase III MLS hardware. If computed in future military hardware (as defined by the draft MMLS specification), it could be used in conjunction with ground speed to compute flight path angle. Since ground speed must be derived in a computer, MLS vertical velocity could be derived in the same computer. This would eliminate the need for a new dedicated receiver output.

Lateral Deviation from the selected azimuth radial is the MLS equivalent to the ILS localizer deviation signal. To make straight-in MLS approaches compatible with existing USAF approach couplers and flight director computers, the MLS lateral and vertical deviation signals must be identical in format to the ILS deviation signals.

MLS lateral deviation with respect to the extended runway centerline (or 0 degree azimuth radial) should be displayed on the course deviation indicator (CDI) during the final approach segment of complex trajectories. This parameter is the primary source of runway centerline guidance both in the air and on the ground.

Vertical Deviation from the selected glide slope angle is the MLS equivalent to the ILS glide slope deviation signal. This parameter is the primary source of vertical guidance during the final approach segment and should be displayed on the glide slope indicator.

MLS Computer Outputs: In order to precisely fly trajectories of more than one lateral and/or vertical segment, the pilot requires information not supplied by the MLS receivers.

A computer is required to calculate: deviations between the aircraft's present position and desired position; distances along the track from the aircraft to the next course or glide path change; and, angles which relate the desired trajectory and the aircraft's position to the runway. Along with these calculations, the computer must provide the proper interface format for the signals to be displayed.

The following parameters can be obtained from the MLS computer, which has as its inputs both the definition of the desired complex trajectory and the MLS related receiver data.

Desired Track Angle is the magnetic course of the particular lateral trajectory segment currently being flown.

For ILS, the desired track angle of the entire approach corresponds to the runway heading. Prior to initiating the approach, the pilot manually sets this angle on his HSI course pointer to properly orient his primary horizontal situation display.

For MLS complex trajectories, the desired track angle changes as the aircraft progresses along the approach (see Figure 29). Based on typical MLS approach profiles flown by the USAF T-39 and NASA 737; three, and sometimes four course changes, can occur during a seven or eight minute approach. Under these types of maneuvering conditions it is important for the pilot to remain constantly oriented with his desired (and computer-commanded) direction of flight. Due to pilot workloads and required path tracking accuracies during this portion of flight, it is recommended that the desired track angle be constantly displayed to the pilot. This can be accomplished, as with present-day RNAV systems, by automatically slewing the course pointer and readout on the HSI via computer commands. Under tracking conditions, this results in a course pointer that is always pointing up. This automatic method has been used quite successfully on the T-39 aircraft. Slewing accuracies of less than 1 degree of track angle have been achieved.

It should be noted that all HSI's do not contain an automatic course slew function. For those aircraft without this function, the MLS integration task must include a tradeoff of HSI replacement costs versus a reduction in MLS capability.

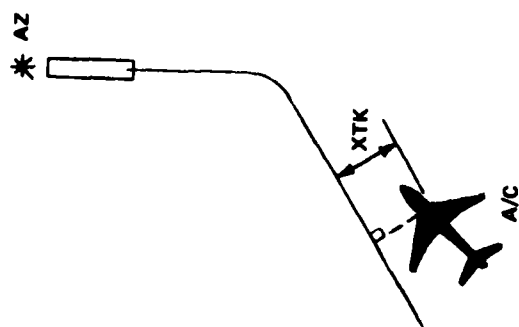
Lateral Deviation, generated within the MLS computer (as

opposed to the output from the MLS receiver), represents the aircraft's crosstrack error from the desired lateral path (see Figure 30a). This signal is the primary reference for lateral axis control during the complex portion of the approach and should be presented on the CDI. The signal should be scaled such that useful information is obtained throughout the entire approach. This results in a conflict due to the need to provide deviation data that is not saturated during the initial capture maneuver yet provides sufficient sensitivity for accurate control during the tracking phase. A solution for this problem, determined in the T-39 program, consisted of making the CDI sensitivity inversely proportional to altitude according to a gain schedule which approximated an ILS localizer signal. Since this display parameter is the primary reference for tracking performance, it is directly associated with obstacle avoidance and air traffic control. For this reason it is recommended that a standard scaling be established for this parameter for all aircraft. Insufficient analysis of this problem was done on the T-39 to warrant recommendation of its solution for this standard.

For the final approach segment of the complex trajectory, the lateral deviation signal on the CDI should automatically switch from the computed crosstrack error to the raw MLS receiver output. This eliminates a source of error introduction (i.e., MLS computer) and enhances the pilot's ability to monitor the approach to touchdown.

Vertical Deviation, generated within the MLS computer (as opposed to the output from the MLS receiver), represents the aircraft's vertical track error from the desired vertical path (see Figure 30b). This signal is the primary reference for vertical axis control during the complex portion of the approach and should be presented on the glide slope indicator. For the same reasons as those described above for the lateral deviation signal, the scaling of this signal should be standardized for all aircraft and the raw MLS receiver vertical deviation output should be automatically switched in for the final approach segment.

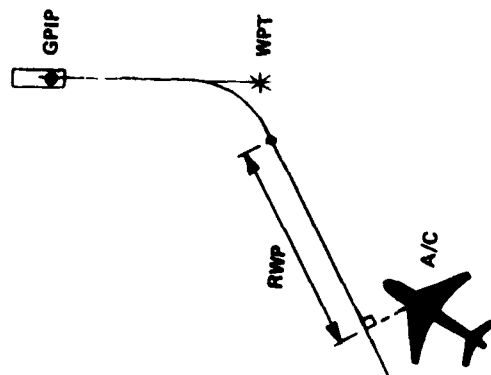
Range-to-Waypoint represents the distance along the desired lateral track from the aircraft to the next waypoint transition (see Figure 30c). This parameter provides the pilot with



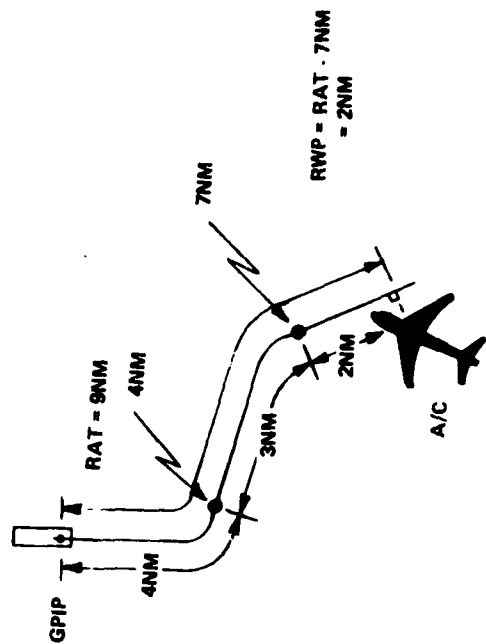
LATERAL DEVIATION (XTK)
Figure 30a



VERTICAL DEVIATION (VTK)
Figure 30b



RANGE - TO - WAYPOINT
Figure 30c



RANGE-ALONG-TRACK-TO-TOUCHDOWN (RAT)
Figure 30d

a key piece of short term orientational information during the complex portion of the approach.

Range-Along-Track-to-Touchdown represents the distance along the desired lateral track from the aircraft to the GPIIP (see Figure 30d). This parameter, like range-to-waypoint, provides significant orientational information for complex approaches. Unlike range-to-waypoint, however, this information can be for both long and short term use and is, therefore, recommended. It is long term since the pilot is continuously informed of his true distance along the desired path to touchdown. It is short term if the approach plate is designed to indicate this parameter at the segment transition points. By a mental subtraction the pilot can quickly calculate his distance to the next waypoint transition (see Figure 30d). Both range-to-waypoint and range-along-track-to-touchdown (only one of these parameters is required) should be presented as discrete numerical information, as is presently done for TACAN DME, on the HSI or a dedicated DME indicator. Like the raw DME information from the MLS DME receiver, the display of this parameter should provide resolution to 0.1 nautical miles.

Bearing-to-Waypoint represents the relative bearing of the aircraft to the next waypoint transition. Like range-to-waypoint, it is significant short term orientational information throughout the complex approach.

Bearing-to-Station represents the relative bearing of the aircraft to the MLS azimuth ground site. This signal is derived from azimuth and aircraft heading information in the MLS computer not in the MLS receiver. This parameter also provides the pilot with significant long-term orientational information of the runway position. Typically, information of this nature is presented on an HSI, RMI, or BDHI bearing pointer.

Flight Path Angle can be accurately derived within the MLS computer by calculating $\gamma = \tan^{-1}(\dot{h}/GSP)$ where: γ = flight path angle, \dot{h} = vertical speed, GSP = ground speed. This parameter is particularly useful in monitoring aircraft performance along multi-segment descent paths defined in terms of flight path angle. For the 2-segment descent

shown in Figure 56b, a display of flight path angle provides the pilot with a quantitative measure of his actual vertical path. If this parameter was easily displayable with present instrumentation, it would be recommended. This is not the case, however, on the USAF aircraft studied for this report. Moreover, sufficient data from the T-39 program does not exist to support the requirement for flight path angle.

Path Anticipator - One of the most serious deficiencies with the current T-39 mechanical display presentations has been the lack of sufficient path anticipation information. At present, to determine what will occur next, the pilot must relate his position to the approach plate to obtain the information. If he could obtain this information directly from his displays and use the approach plate only for monitoring, his workload would be reduced. The ultimate in path anticipatory information can, of course, be provided with an electronic map display; however, its presentation on mechanical displays is more difficult to implement within an overall system's framework. The following discussion highlights two methods for providing lateral path anticipation using the HSI. Each method has possible problems and variations.

The first method involves stepping, or rapidly slewing, the course pointer at the start of the circular transition to the course of the next lateral path segment. On the T-39 presently, the course pointer slews at a rate proportional to the path's radius of turn and the aircraft's true turn rate. The problem occurs in that the pilot does not immediately know when it will stop slewing). At the same time, the lateral deviation indication could be referenced to the next segment and therefore step to the newly computed error. The problem with this system operation is that the circular arc is a definite part of the trajectory and not just any transition from one straight path segment to another. Therefore, the deviation shown must be referenced to the desired circular arc. This criterion is substantiated by present day approaches such as the Carnarsie approach (Figure 29) at John F. Kennedy International in New York which has a defined 3.7 nautical mile radius turn on to a 2 nautical mile final approach leg. In this approach the prescribed transition between straight path segments is an important portion of the approach.

A variation of this method would involve stepping, or rapidly slewing, the course pointer at the start of the circular transition but keeping the deviation referenced to the circular arc instead of changing the reference to the next segment. Therefore, at the transition, no step would occur on the lateral deviation indicator. The problem with this method is that ambiguous situation information would result. For example, if a 45 degree course change occurred at the transition and the aircraft was on track and turning to maintain the circular arc, the situation would appear as a 45 degree (decreasing to a 0 degree) crab angle with zero lateral deviation.

A second, more desirable, method is to step, or rapidly slew, the heading bug to the next course to be flown, and allow the course pointer and lateral deviation indicators to operate as at present. The bug can be slewed either at the start of the circular arc or at the completion of the circular arc. This method will provide the desired path anticipation without sacrificing the need for accuracy about the circular arc or introducing confusing situation indications.

A possible drawback to this second method involves its relation to missed approach procedures. At present in many commercial aircraft, the heading bug is normally set to the missed approach heading when executing ILS approaches. In the military, however, this is not necessarily standard procedure. If it is required, a system problem results since the bug movement is under computer control for a different function. Although the computer could provide auto-slewing of the heading bug to the missed approach heading upon selection of a go-around mode, this would require increased data entries and would result in further complication in failure effects analyses and safety considerations.

Aircraft Position Predictor is a display parameter commonly used with CRT map displays. It is represented in the form of a "whip-type line" which indicates aircraft movement, over a fixed time segment (typically 7 to 15 seconds for MLS approach conditions), with respect to the desired path. It essentially acts like a flight director roll command bar. Further information is contained on this subject in Appendix B.

Ground/Wind Speed and Direction, Estimated-Time-To-Go-

These parameters are easily derived within the MLS computer as part of the aircraft position computation for complex trajectory flight. They provide the pilot with reference type information that is not essential during high workload situations. For present RNAV and OMEGA systems, this information is typically selectable for display on a CDU. This method of display is also recommended for MLS.

3.3.3 MLS Auxiliary Data Parameters

The MLS provides the capability for transmitting many ground-derived parameters to the aircraft as auxiliary data information. This data consists of: status information which is useable by the pilot for reference; and, geometry data which describes the layout of the MLS transmitters and is required by the MLS computer in the complex trajectory flight computations. Although the final auxiliary data parameters to be provided have not been defined, the following lists provide some examples.

3.3.3.1 Auxiliary Data Status Information

Runway Heading	Runway Visual Range
Runway Condition	
(e.g., wet, dry)	Ceiling
Runway Status	
(e.g., CAT I, CAT II)	Barometer Setting
Runway Length	Wind Velocity on Runway
Minimum Glide Slope	Wind Direction on Runway
Azimuth Sector Limits	Wind Gust Velocity on Runway
Facility Identification	

3.3.3.2 Auxiliary Data Geometry Information

Elevation Antenna Height
Distance Along Runway from DME Site to GPIP
Distance Along Runway from Azimuth Site to GPIP
Elevation Site Offset from Runway Centerline
Elevation of GPIP Above Sea Level
DME Site Offset from Runway Centerline

3.3.4 MLS Alerts and Warnings

MLS related alerts and warnings shall provide a positive indication of failures, loss of adequate signal strength, important ground facility information changes, and upcoming approach segment transitions. These indications shall be provided on primary instrumentation and master caution and warning panels in a manner similar to corresponding ILS and RNAV information. The alert and warning information discussed below is readily available for display. The MLS receiver validity data is also useable in the MLS computer and autopilot: to enable mode engagement; to cause reversion to dead-reckoning control; and; to automatically disconnect the autopilot during autoland control.

The MLS receivers output validity information in both a standard 28 VDC analog format and a digital format. The analog format is required to allow interface with standard electro-mechanical instrumentation and existing autopilot/flight director systems. The digital format is cost-effective in interfacing with the digital MLS computer. The receiver validities - azimuth, elevation, DME and back azimuth - are a function of received signal strength and receiver self-testing. Invalid information can be displayed with flags on the ADI, HSI, and MLS AZ/DME indicator.

In complex trajectory flight, a dead-reckoning mode can be engaged as a function of loss of receiver validity. Control equations during this mode are based on position data derived from the last good MLS and wind speed information. Although this results in significant inaccuracies as time goes on, on a short term basis it solves the problem of intermittent signal strength due to antenna masking. Use of dead-reckoning during complex approaches to landing for periods of time greater than 10 seconds should be avoided. Flag information associated with the raw MLS receiver data provides an indication of the faulty parameter. A discrete light should be provided on the CDU for annunciating the mode.

A discrete light is required on the master caution and warning panel to indicate a change in important ground facility information per the MLS auxiliary data transmission. Important information changes which require review by the pilot include runway condition, runway status, RVR, ceiling and significant wind changes. Logic may be required within the computer to determine when the light should be illuminated.

A discrete light is also required to alert the crew of upcoming segment transitions in both the lateral and vertical axes. This should be placed in the primary instrument area to insure visibility. RNAV annunciations of this alerting function result in a flashing indication for 15 seconds immediately preceding each transition point. This method of annunciation is also useful for MLS.

3.4 Man/Machine Interface Requirements

3.4.1 Control Functions

The man/machine interface with MLS is a variable problem dependent on the level of MLS capability employed. For simple straight-in MLS approach paths the procedures involved with setting up the approach are consistent with those for ILS. As the approach path complexity increases, so does the pilot procedural requirements. For an avionics configuration which contains full MLS complex trajectory capability, the following MLS-related control functions are required. A discussion on each of these functions immediately follows.

Data Entry	Antenna Mode Select
Channel Select	Complex Trajectory Mode Select
Audio Volume Adjust	Auxiliary Data Select
ILS/MLS Select	

3.4.1.1 Data Entry

Data Entry involves insertion of the required data into the MLS computer to totally define the desired trajectory. Depending on the complexity of the trajectory and the method of insertion and crosscheck, data entry can be a major source of pilot workload simply due to the number of entries which have to be made. The means of data entry traditionally involves some form of CDU made up of alphanumeric readouts, pushbuttons, lights, and a keyboard or rotary encoder knob. Such a CDU is required for MLS complex trajectory flight.

Unlike RNAV operation, where the pilot has a reasonable amount of time to set up and stay ahead of his flight plan (usually done on the ground prior to the flight), MLS operation will require the pilot to enter the trajectory data after obtaining clearance from approach control. Different methods exist which can automate or semi-automate this task. These include:

automatic data entry via a card reader; onboard bulk storage which can be accessed in flight and is modifiable through a tape reader on the ground; a ground-to-air data link system; and, manual entry of small amounts of data required to define a limited set of standardized trajectories. Although the automatic schemes end up creating expensive logistic problems and none totally solve the problems created by last minute changes directed by traffic control, they do require serious consideration since they drastically reduce pilot workload levels for a large percentage of the time. The manual entry scheme with standardized trajectory types also must be considered since it will reduce both initial purchase cost and system maintenance costs for the user. Further discussions on these methods follow:

- Automatic Data Entry Unit (ADEU) - A prepunched IBM card, programmed for the desired trajectory, is inserted into the ADEU to automatically enter the required data. A logistics problem associated with this method results from the need to continuously carry and maintain a large library of cards corresponding to all of the possible trajectories at all airports and alternates along the route or mission structure. It is assumed that each landing field will have between 5 and 10 standard trajectories for each MLS runway.
- Flight Data Storage Unit (FDSU) - This unit provides bulk storage memory which can be altered by tape via a self-contained tape reader. In this manner all trajectory data for a region of airports is stored in memory by trajectory number. To access this memory, the pilot must only insert the required trajectory number on the CDU. The problems involved with this method are similar to those with the ADEU.
- MLS Auxiliary Data - Trajectory data could be defined on the ground and transmitted to the aircraft as part of the MLS auxiliary data information. The pilot would only have to verify this data on his CDU. The problem with this method lies in the fact that the MLS auxiliary data is only available inside MLS coverage. Workload and traffic control problems would certainly result during the period

of time when the data check was being made and the MLS was essentially being ignored.

- Discrete Address Beacon System (DABS)- Since this is a long-range ground-to-air transmission (50 nm), DABS would tend to eliminate the problems associated with the MLS data link. Like MLS, this system is in its development stages. Its use for this application requires further investigation into the technological and cost aspects of its implementation.
- Manual Entry of Standardized Trajectory Type Data - This method probably provides the most cost-effective near term solution to the data entry problem. It requires the definition of standardized trajectory types with a limited number of variables required for entry. Detailed discussions on this subject are included in Section 4.3.

One of the major problems associated with complex trajectory flight is determining whether the trajectory computed by the MLS computer is truly the trajectory which the pilot intended to fly. The two major sources of error are those introduced by: the pilot in specifying and inserting the defining data to the computer; and, faults within the computer itself.

Note that in the alternate method of defining trajectories discussed in Section 3.1, only one point on the trajectory was defined with respect to the MLS transmitters - the touchdown point. The remainder of the trajectory was defined by laying out the next segment with respect to the touchdown point, then the next segment was defined with respect to the previous one, etc. It becomes clear that if a multi-segmented trajectory is defined in this manner, any error in specifying one segment will result in the wrong location of every segment which follows it.

In this manner, a single checkpoint situated on the outermost inbound leg of the trajectory can be used to check the validity of the entire trajectory. This checkpoint will be input to the computer as an along track distance only. From the trajectory it has defined, the computer can compute the coordinates of this point in terms of the basic MLS receiver outputs (i.e., with respect to the transmitters)

and this information can be supplied to the CDU for presentation.

By comparing these basic coordinates to those shown for the checkpoint on the approach plate, the pilot may now conclude that:

- 1) The data was entered correctly
- 2) The trajectory is correctly computed within the MLS computer

This is an extremely valuable confidence check and obviates the need for the pilot to check each data insertion independently. It thereby represents a significant decrease in pilot workload in interfacing with the CDU.

Having once visually checked that the trajectory is correct, the pilot may now cause the displayed checkpoint data to be stored in the MLS computer. The computer will now periodically recompute the trajectory and checkpoint data and compare the results to those previously verified by the pilot. In this manner, a subsequent failure can be detected by the computer and an automatic alarm can be issued.

Data entry equipment, for USAF aircraft retrofitted for MLS complex trajectory flight, will probably consist of a dedicated MLS CDU rather than a modified NAV or weapons delivery CDU. This will eliminate the need for extensive redesign investigations and rework of many different existing pieces of equipment. It will also result in an increased amount of MLS commonality within the USAF inventory since the CDU can be standardized for those aircraft requiring full complex trajectory capability. MLS data entry requirements for future USAF aircraft can certainly be integrated into the multi-function keyboard concepts developed under the Digital Avionics Information System (DAIS) program by the Air Force Avionics Laboratory at Wright Patterson Air Force Base.

3.4.1.2 Channel Select

Setting of the MLS angle and DME frequencies involves selection of the proper MLS channel number. Although to the pilot this only involves selecting a number from 001 to 200 via a rotary knob, keyboard, or any other device, consideration must be given to implementing this mechanism in a manner which

provides maximum availability of the basic MLS. Part of this consideration must include a reliability analysis tradeoff of the components in the CDU (and computer, if applicable) involved with the channel selection process and those of a simplified tuner completely independent of the CDU. The results of this analysis will determine whether the channel select function should be implemented as part of the complex CDU or in a highly reliable simple tuner. This analysis has not been performed for this study.

3.4.1.3 Audio Volume Adjust

Either two knobs or one dual-concentric knob are required to adjust the volume of the audio identification signals from the angle and DME receivers. This control should be located adjacent to the channel selection mechanism due to its relationship to the tuning process.

3.4.1.4 ILS/MLS Select

For aircraft that contain both ILS and MLS capability, a switch is required to differentiate between the systems. This is used to switch display information and provide interlock logic to the MLS navigation computer and autopilot/flight director systems.

3.4.1.5 Antenna Mode Select

For those aircraft flying complex trajectories which require more than one C-band and L-band antenna to eliminate masking (as experienced on the USAF T-39 and NASA 737), an antenna switching unit is required. This switch should operate in an automatic mode based on received signal strength for the complex portion of the approach. On final approach it must be locked on to the front antennae to ensure a constant flight path and ground clearance level. This is especially true for large aircraft where the distances between fuselage-mounted front and rear antennae can result in vertical path discrepancies of 12 feet for normal approach pitch attitudes.

An override control may be necessary for the automatic switching unit. This need is dependent on the reliability levels of the switching unit and the receiver electronics used to drive the switching unit. If these levels are sufficiently high, the antenna mode select switch is not required. If not, the switch should be included with the unit which contains the channel select mechanism.

3.4.1.6 Complex Trajectory Mode Select

This switch is required to differentiate between a straight-in ILS-type MLS approach and a complex trajectory. It should be integral to the CDU. The resultant switching external to the MLS computer and CDU should be configured such that straight-in MLS approaches are always possible with a CDU and/or computer failure.

3.4.1.7 Auxiliary Data Select

MLS auxiliary data is necessary for complex trajectory flight due to the runway and ground site geometry information it provides. Its usefulness for display information is questionable especially for direct ILS replacement configurations. For this reason a dedicated auxiliary data panel is not recommended. Instead, it is recommended that this information be provided on a CDU if found to be necessary. Its implementation within the CDU requires a pushbutton to call-up the various pieces of information. Also required, in relation to this data, is a warning light which indicates that a change has occurred in the ground status information. This warning should probably be provided on the aircraft's master caution and warning panel to catch the pilot's attention and direct him to look at his auxiliary data information.

3.4.2 ILS/MLS Procedures

Pilot operational procedures for straight-in ILS-type approaches are essentially identical for ILS and MLS configured aircraft. For MLS complex trajectory flight, data entry and approach situation monitoring are the primary reasons for the increase in pilot workload. Three general sets of procedures are shown below which point out the similarities and differences of the set-up requirements for the three types of approaches.

STRAIGHT-IN

- | <u>ILS</u> | <u>MLS</u> |
|--|---|
| 1) Tune ILS frequency -
(2 knobs) | 1) Select MLS channel -
(1 knob or 4 keystrokes) |
| 2) Identify-volume control
(1 knob) | |
| 3) Select intercept heading
(1 knob) | |

- 4) Select final approach course
(1 knob)
- 5) Select ILS mode:
 - a) Set ILS/NAV/ TAC switch to ILS
 - b) Depress ILS pushbutton
- 5) Select MLS mode:
 - a) Set ILS/NAV/TAC switch to ILS *
 - b) Set ILS/MLS switch to MLS
 - c) Depress ILS * pushbutton

* ILS nomenclature should be changed to APPR (approach)

COMPLEX TRAJECTORY

- 1) Select MLS channel - (1 knob or 4 keystrokes)
- 2) Identify - (dual concentric knob)
- 3) Enter trajectory data - (1 pushbutton and 12 entries of up to 4 keystrokes each * to define a trajectory with 3 lateral and 2 vertical segments)
- 4) Check trajectory data - (1 entry and reading and comparing 3 numbers versus those on the approach plate)
- 5) Select complex trajectory MLS mode
 - a) ILS/NAV/TAC switch to ILS**
 - b) ILS/MLS switch to MLS
 - c) Depress complex trajectory mode pushbutton
 - d) Depress ILS** pushbutton

* Based on third CDU candidate described in Section 4.3

** ILS nomenclature should be changed to APPR (approach)

In comparing these procedures, the only difference for the straight-in ILS and MLS approaches is the additional ILS/MLS switch operation. This is insignificant in terms of workload.

For the complex trajectory procedures, however, data entry and check requires 13 additional operations of up to 4 key-strokes each and the actuation of two additional pushbuttons. These numbers are based on what is probably the most complex, and yet still practical, approach that will be used (i.e. 3 lateral and 2 vertical segments). They are also based on a specific CDU which is not optimized for the lowest number of entries. For a less complex approach consisting of two lateral and one vertical segment, only six rather than 13, additional entries are required. It should be noted that these numbers of entries include runway heading and runway height above sea level. Although this information

will be included as MLS auxiliary data, it must be entered into the computer prior to entering signal coverage to allow performance of the data entry check procedure.

Although workload levels for the complex trajectory approach are obviously much higher than those for the straight-in, no problem is expected in two-seat aircraft if approach definition is obtained from traffic control a sufficient distance from the approach initiation point. If this time is not provided or if the approach requirements are altered close to the airport, the new approach must be sufficiently simple to allow rapid entry or the pilot will be required to enter a holding pattern to complete his data entry. If this occurs for a single-seat aircraft, the procedures must allow for a rapid reversion to a straight-in approach.

4.0 MECHANICAL/ELECTRONIC CONTROL-AND-DISPLAY CANDIDATE CONFIGURATIONS

4.1 General MLS Configurations and Electro-Mechanical Display Candidates

Four general MLS configurations have been defined as an aid in analyzing the overall MLS requirements for all classes of USAF aircraft and in performing the aircraft studies of the C-130A/D, F-111A/E, A-7D, F-15A, and KC-10A. The intent is to recommend one of the four general configurations for each of the specific aircraft. Recommendations will be based on present aircraft systems' capabilities, complexity of retrofit, and anticipated pilot workload levels with the associated cockpit controls and displays. The four general configurations have been labelled as follows:

- MLS-1 Direct ILS Replacement
- MLS-2 Selectable Azimuth and Elevation
- MLS-3 Selectable Intercept of Final
- MLS-4 Complex Trajectory

Configuration complexity increases significantly from the direct ILS replacement system to the complex trajectory system. The increased complexity is evident in the control/display design requirements, resulting hardware requirements, and increase in pilot workload for operation. Highlights of these configurations follow. A detailed discussion of these configurations is included in the following sections.

- MLS-1, Direct ILS Replacement Configuration:
 - Angle receiver, C-band antenna, and tuner required
 - DME function optional depending on usage of marker beacon
 - Auxiliary data function optional
 - Raw azimuth and elevation deviation outputs identical in format to present ILS receiver outputs to insure compatibility with present USAF autopilot/flight director equipment and instrumentation
 - Raw deviation outputs referenced to extended runway centerline and nominal glide slope

- of field
 - No selectable azimuth and/or elevation angles
 - Useful for all classes of aircraft
- MLS-2, Selectable Azimuth and Elevation
 - Required and optional equipment same as for MLS-1 (i.e., angle receiver, antenna and tuner required; DME and auxiliary data functions optional).
 - MLS tuner requires selection mechanisms for selecting desired azimuth and elevation angles as in Phase III MLS design
 - No low altitude IFR use seen for selectable azimuth function
 - Selectable elevation function useful for STOL and rotary wing aircraft in performing steep final descents. No use seen for CTOL aircraft.
- MLS-3, Selectable Intercept of Final
 - Angle receiver, DME interrogator, C-band and L-band antennae, and switching unit required
 - Also requires MLS navigation coupler, simple control panel, and azimuth/DME display
 - Auxiliary data functions optional
 - Provides precise low altitude IFR control along a selectable heading intercept and to a selectable final approach segment length
 - Provides 2-segment glide path capability
 - Allows close-in (< 2 nm) final approach captures not possible with typical present day ILS approaches (7-10 nm)
 - Useful for all classes of aircraft
 - Particularly useful for providing limited complex trajectory capability while maintaining sufficient operational simplicity for single-seat aircraft.
- MLS-4, Complex Trajectory Configuration
 - Requires angle receiver, DME interrogator, and switching unit as in MLS-3
 - Requires fore and aft antenna installations and antenna switching unit, if desired trajectories warrant

- Requires more complex MLS navigation computer
- Requires azimuth/DME display
- CDU replaces control panel and contains auxiliary data functions
- Provides precise low altitude IFR control along any complex trajectory
- Increase in capability results in increase in pilot workload for trajectory selection and monitoring approach progress
- Use for single-seat aircraft without automatic approach coupler and some form of automatic trajectory selection is doubtful due to workload requirements.

4.1.1 MLS Interface Analysis

Although only five different types of USAF aircraft were studied in detail for this investigation, this interface analysis is a comprehensive assessment of the MLS integration problem for most aircraft in the USAF inventory. Detailed discussions for the five aircraft studied are presented in Section 5.0 of this document.

The basic MLS airborne system (as defined for this study) results in a direct replacement for ILS. As various "options" are added additional capabilities are realized, of which, the most sophisticated is complex trajectory flight. Figure 31 shows a generalized representation for the basic system. It consists of a C-band antenna, an angle receiver, a means to tune frequency channels, and a volume control to adjust the audio identification signal. To complete the loop, means must be provided to display and utilize the MLS receiver outputs (deviations, validities and audio signals). In general, these means are available in all existing USAF aircraft equipment systems.

The MLS angle receiver must provide analog deviation and validity signals with interface characteristics identical to those of the localizer and glide slope signals of the present ILS system. This is required so that a retrofit involving the minimum MLS capability requires no modifications to existing autopilot/flight director computers (i.e., changes to control law gains, input impedances, etc.) and/or cockpit instruments. Additionally, the MLS receiver provides a digital output data bus with full coverage aircraft position

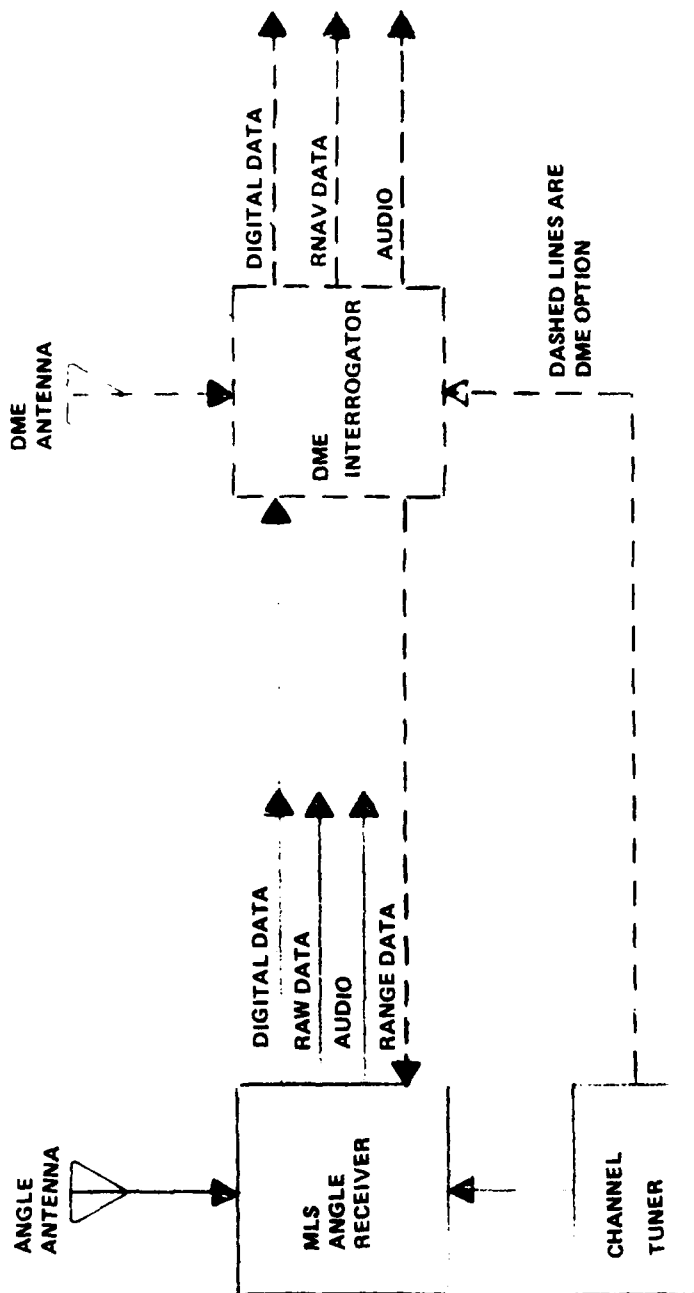


Figure 31 Basic MLS System With DME Option

and auxiliary data information for those aircraft which will more fully utilize the MLS capabilities.

If a DME antenna and interrogator are added to the basic MLS system to increase capability, range and altitude information are available on a digital data bus. This information can be displayed on a cockpit indicator for the basic system, and/or can be processed with the angle receiver data by a suitable computer to provide precise aircraft position in rectangular coordinates for complex trajectory flight.

The overall implementation considerations, for the interface of the equipment and systems associated with any level of MLS retrofit capability, can be classified in the following categories:

- Additions
- Modifications
- Replacements

"Additions" include new ship's wiring, new MLS equipment, and the physical location and mounting details of the new units. "Modifications" include the re-routing and re-termination of existing wires, and the modification of existing units. "Replacements" include replacement of existing units in the cockpit and the equipment bay.

For any aircraft, the general MLS interface illustrated in Figure 32 is applicable. Functions of the MLS are shown in their logical relationship with each other and with the existing system. MLS receiver outputs are: routed through the MLS interface for further computation and/or signal formatting; applied to any new MLS displays; and, via the existing interface, applied to the flight controls, instruments, and audio system.

Typical equipment associated with each function is listed in the tables adjacent to each function block. All equipment associated with the MLS functions are additions. Equipment listed under the existing interface function are exclusively in the modification category since ship's wiring associated with these units may be altered. Most of the remaining equipment listed under flight control, instruments and audio will be left intact since the MLS shares these with other systems that may have a higher

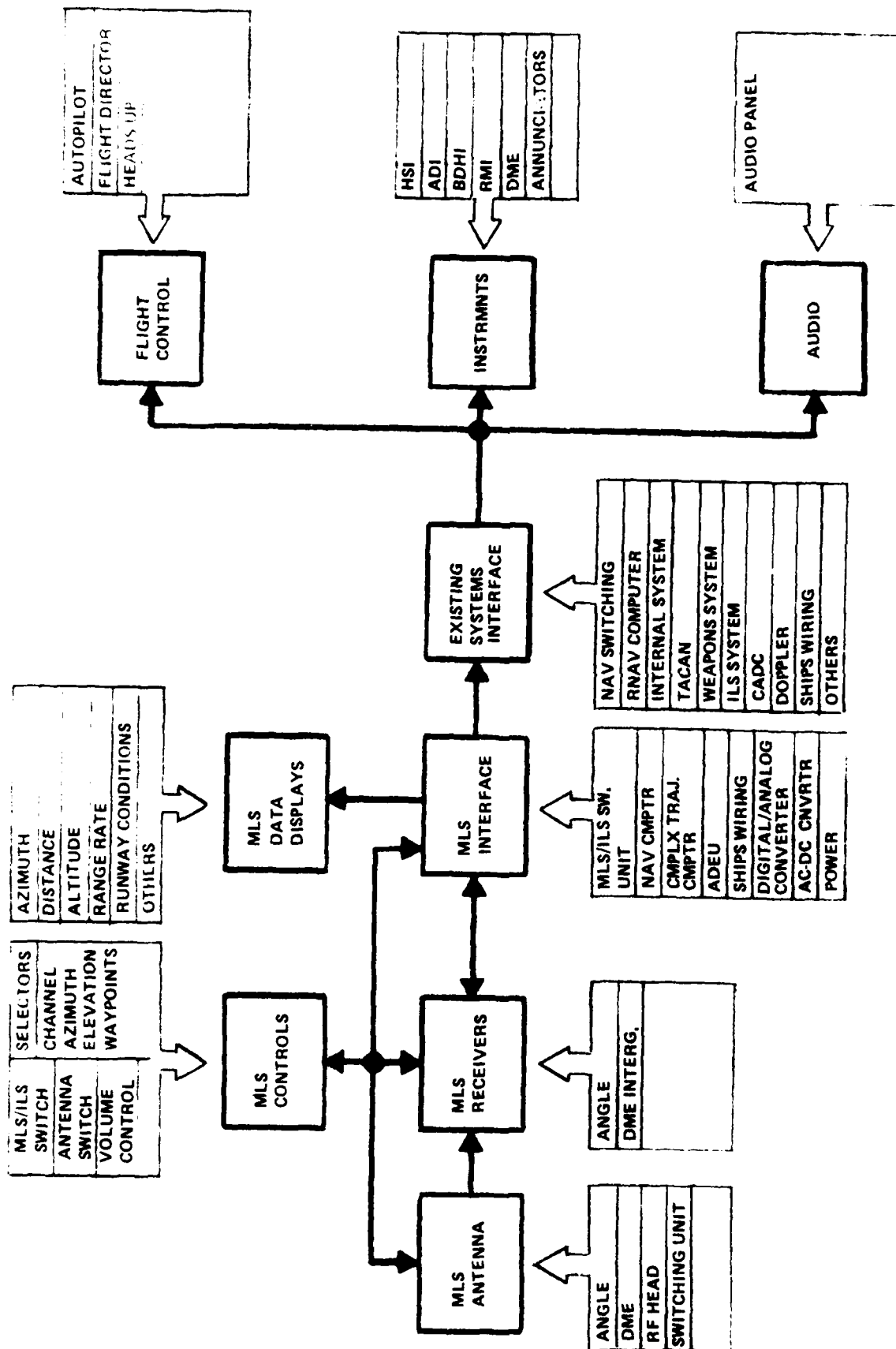


Figure 32 MLS General Interface

mission priority. Simple modifications may be required for a few of these units and replacements will be confined to updated or more sophisticated units required to perform the MLS task.

The analog MLS outputs are useable "as-is" by the existing system, while the digital signals require either conversion or must be combined with other signals and then modified for flight path control. All DME interrogator output signals are in digital form and a digital-to-analog converter is required for analog display interfacing. Since the raw deviation data outputs of the MLS angle receiver are compatible with the existing ILS system, these outputs can be utilized as a function of MLS selection. Normal "ILS type" approaches can be made using the present flight controls and instruments.

If an MLS-controlled complex approach capability is required, an interface unit is necessary to process the full-coverage digital outputs, and, thereby, provide deviation signals for the instruments and steering signals for the flight controls. Two interface possibilities are feasible. The first is to provide a dedicated (new) digital MLS navigation computer, and the second is to modify a suitable computer already installed (major modification) in the aircraft.

Providing an MLS navigation computer is advantageous since a common computer can probably be used for all aircraft which require complex trajectory capabilities. Furthermore, some aircraft are not equipped with digital computers or have computers that cannot be easily modified due to space, power, memory or real-time limitations.

Modification or a functional replacement of existing computers is advantageous since a new unit need not be installed. For aircraft with space and weight limitations, this may be the only choice. Some of the disadvantages of this approach to retrofit are as follows:

- Many different types of computers will have to be studied and modified
- Each modification will require coordination with a different manufacturer
- Test equipment and specifications associated

- with each computer must be modified
- As a result of the above, the USAF management task is greatly increased

Because of its disadvantages, the computer modification approach is not generally recommended except for aircraft types with severe space limitations. As a consequence of eliminating this approach, only minor equipment changes and ship's wiring are involved in the "modifications" category. Wherever possible, even minor equipment changes will be avoided. The "modification" task is to provide MLS outputs to the audio system, flight controls and instruments.

Since the DME and angle receiver audio signals are "paralleled" on a common audio output and individual signals are introduced by dedicated on-off switches and volume controls; the existing wiring need not be interrupted, and the audio wires can be considered as "additions." A separate switch (on, off) is required for each audio signal. If space is available on existing audio panels, the switches should be added there. If space is not available, a simple panel must be added somewhere in the cockpit.

The sensor information applied to the flight controls and instruments is time shared by the various navigation systems installed on the aircraft. All aircraft utilize ILS and TACAN systems and, as required, more sophisticated navigation systems. Switching of the navigation references can be a function of a separate switching unit or as part of some other unit of the existing interface.

Since the MLS and ILS systems will never be used simultaneously, and the output signals have the same characteristics; the MLS signals will be substituted for the ILS signals when the MLS mode is selected. If both MLS and ILS are to be accommodated on a particular aircraft, an MLS/ILS switch and remotely located switching unit will be added. The existing switching will be left intact, and only the required wires will be interrupted. A typical interface is illustrated in Figure 33. If the ILS system is removed, MLS signals are substituted directly. Switching from MLS raw deviation data to complex trajectory MLS signals will be a function of the MLS interface which is unique for each of the four MLS configurations.

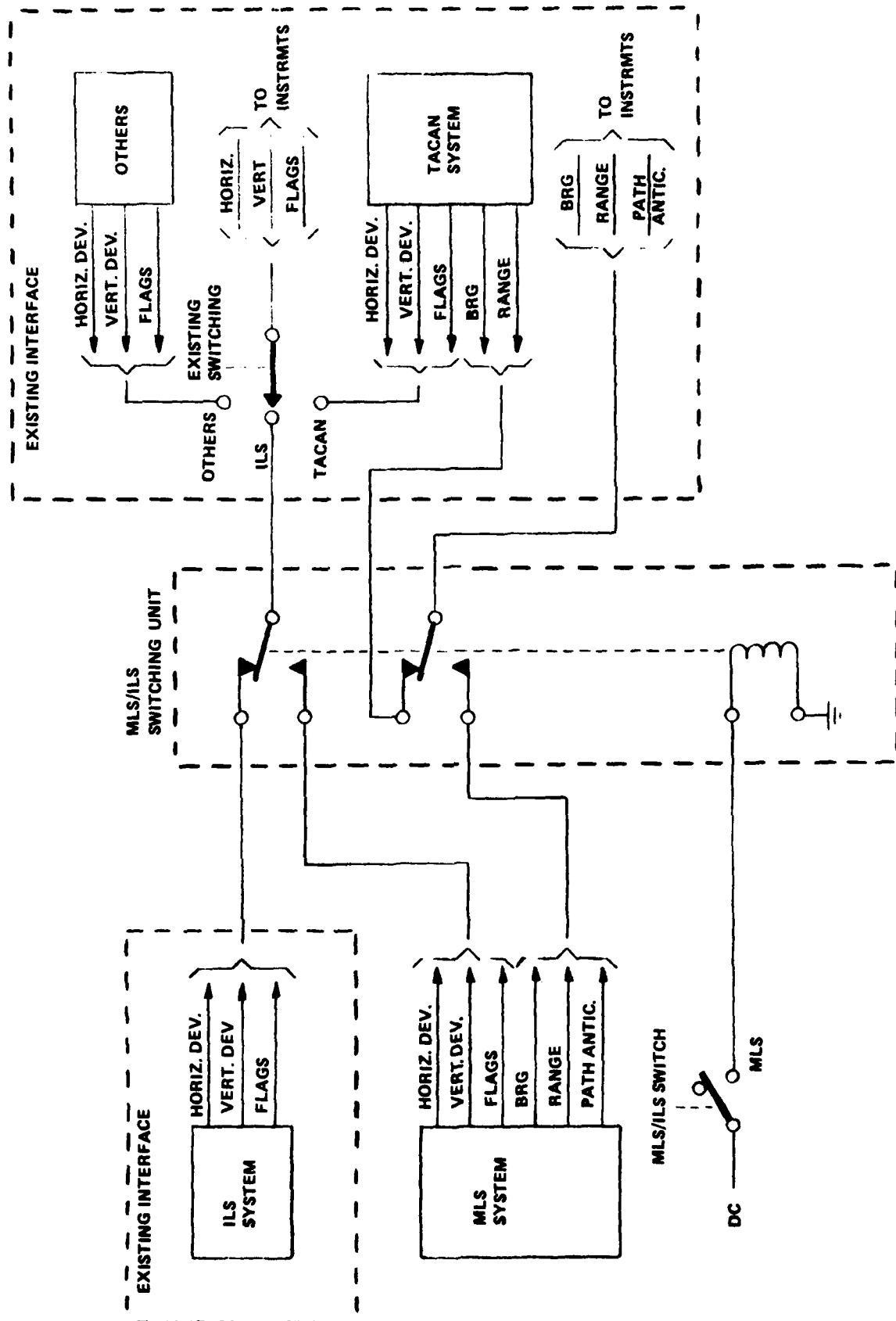


Figure 33 Typical Interface

4.1.2 MLS Configurations

Dependent on the desired requirements and/or the inherent capabilities of a particular aircraft, at least one of the MLS system configurations can be incorporated. The selected configurations are as follows:

- MLS-1 Direct ILS Replacement
- MLS-2 Selectable Azimuth and Elevation
- MLS-3 Selectable Intercept of Final
- MLS-4 Complex Trajectory

All configurations utilize the basic MLS system (see Figure 1). The channel tuner is absorbed by the MLS control panel or CDU as the system's sophistication is increased. The basic MLS system is as follows:

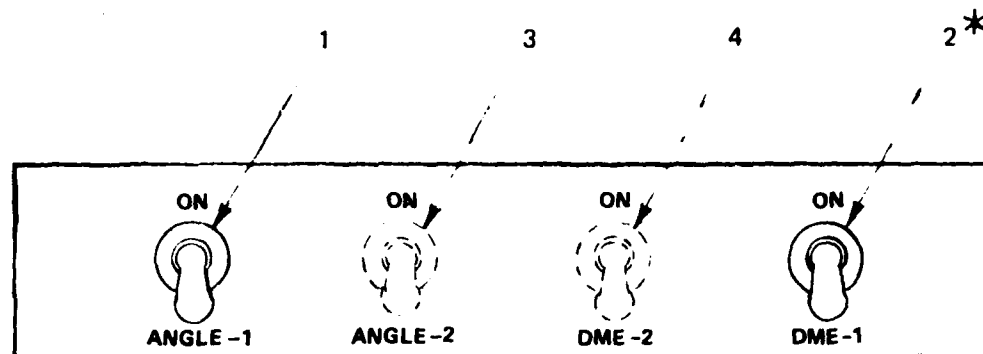
<u>Basic</u>	<u>Basic Options</u>
MLS Angle Antenna	AZ/DME Display
MLS Angle Receiver	Aux Data Display
MLS/ILS Switch	DME Interrogator
MLS/ILS Switching Unit	DME Antenna
MLS Audio Panel	
Channel Tuner	

DC power must be supplied to the MLS components via circuit breakers. Dual MLS installations will require two separate circuit breakers connected to two independent power sources.

The MLS/ILS Switch can be incorporated on the same panel as the tuner.

A typical audio panel (see Figure 34) must be added for all configurations if the MLS on-off audio switches cannot be accommodated on the existing audio panel(s).

The following is a brief description of each of the four configurations, the equipment required and a general



NOTE: FOR DUAL INSTALLATIONS EITHER DASHED SWITCHES OR ADDITIONAL PANEL ADDED.

* NOT REQUIRED FOR BASIC MLS SYSTEM RECEIVER

1. MLS ANGLE-1 SWITCH COUPLES AUDIO SIGNAL FROM ANGLE RECEIVER NO. 1 TO AUDIO SYSTEM.
2. DME-1 SWITCH COUPLES DME AUDIO SIGNAL FROM DME INTERROGATOR NO. 1 TO AUDIO SYSTEM.
3. MLS ANGLE-2 SWITCH COUPLES AUDIO SIGNAL FROM ANGLE RECEIVER NO. 2 TO AUDIO SYSTEM (SEE NOTE).
4. DME-2 SWITCH COUPLES DME AUDIO SIGNAL FROM DME INTERROGATOR NO. 2 TO AUDIO SYSTEM (SEE NOTE).

Figure 34 Typical MLS Audio Panel

discussion of the interfacing. In the description, the equipment added is for a single Category I installation. Category II and III installations require certain dual units. Table 5 lists the equipment complement for Category I, II, and III versions of the four MLS configurations.

Category I systems require either an autopilot or flight director coupler. With this system IFR approaches can be made down to an altitude of 200 feet. Most older types of aircraft fit into this category.

Category II systems require the following:

- Two independent flight director couplers or
- Two independent autopilot couplers or
- Independent flight director and autopilot couplers

All other equipment needed for the approach such as receivers, instruments, etc., must be dual. In addition, the couplers must have certain performance characteristics relating to path tracking under various wind conditions. Equipment on older aircraft does not have these capabilities; and, if Category II capabilities are required, the couplers must be updated. Category II IFR approaches can be made down to an altitude of 100 feet.

Category III systems require the same complement of equipment as Category II systems, and in addition, the autopilot must have automatic flare capabilities. Category III coupled approaches can be made to touchdown and beyond. Various levels of Category III configurations (Category IIIa, IIIA, IIIB, IIIC) are generally defined but these do not affect the MLS system complement of equipment.

4.1.2.1 MLS-1 Direct ILS Replacement Configuration

This is the minimal (basic) MLS system and is a direct replacement for the present ILS system. The required equipment and approach considerations are illustrated in Figure 35. Only the raw data analog outputs of the angle receiver are utilized. It is proposed that the raw data be permanently referenced to the 0 degree azimuth angle and the nominal field elevation angle so that a pilot selection is not required. An option to provide this

TABLE 5
MLS Equipment

		MLS AVIONIC CONFIGURATION							
		MLS-1		MLS-2		MLS-3		MLS-4	
		ILS REPLACEMENT		SELECT AZ & ELEV		SELECT INTERCEPT & GS		COMPLEX TRAJECTORY	
		CAT		CAT		CAT		CAT	
		I	II/III	I	II/III	I	II/III	I	II/III
ANTENNA	ANGLE	1	2	1	2	1	2	1	2
	DME	1	½	1	½	1	2	1	2
		-	-	-	-	-	-	1	2
RCVR	ANGLE	1	2	1	2	1	2	1	2
	DME INTERROGATOR	1	½	1	½	1	2	1	2
CONTROLS	SWITCH	MLS/ILS SWITCH	1	1	1	1	1	1	1
		MLS/ILS UNIT	1	2	1	2	1	2	2
		MLS AUDIO	1	2	1	2	1	2	2
	SELECT								
		TUNER	1	1	-	-	-	-	-
		TUNER/SELECTOR	1	1	1	1	1	1	1
		CONTROL/DISPLAY UNIT	-	-	-	-	-	1	1
		AUTO DATA ENTRY UNIT	-	-	-	-	-	1	1
	DISPLAY	AZIMUTH/DME	1	½	1	½	1	½	½
		AUX DATA	1	½	1	½	1	½	-
	CMPTRS	NAVIGATION	-	-	-	-	1	2	-
		NAV (COMPLEX TRAJ)	-	-	-	-	-	1	2
MISC	AC-DC CONVERTER		1	2	1	2	1	2	2
	DIGITAL/ANALOG CONV.		1	½	1	½	-	-	-
	REMOTE RF HEAD		-	-	-	-	-	1	2

OPTIONAL

MISC. ONLY IF REQUIRED DEPENDING ON SPECIFIC AIRCRAFT

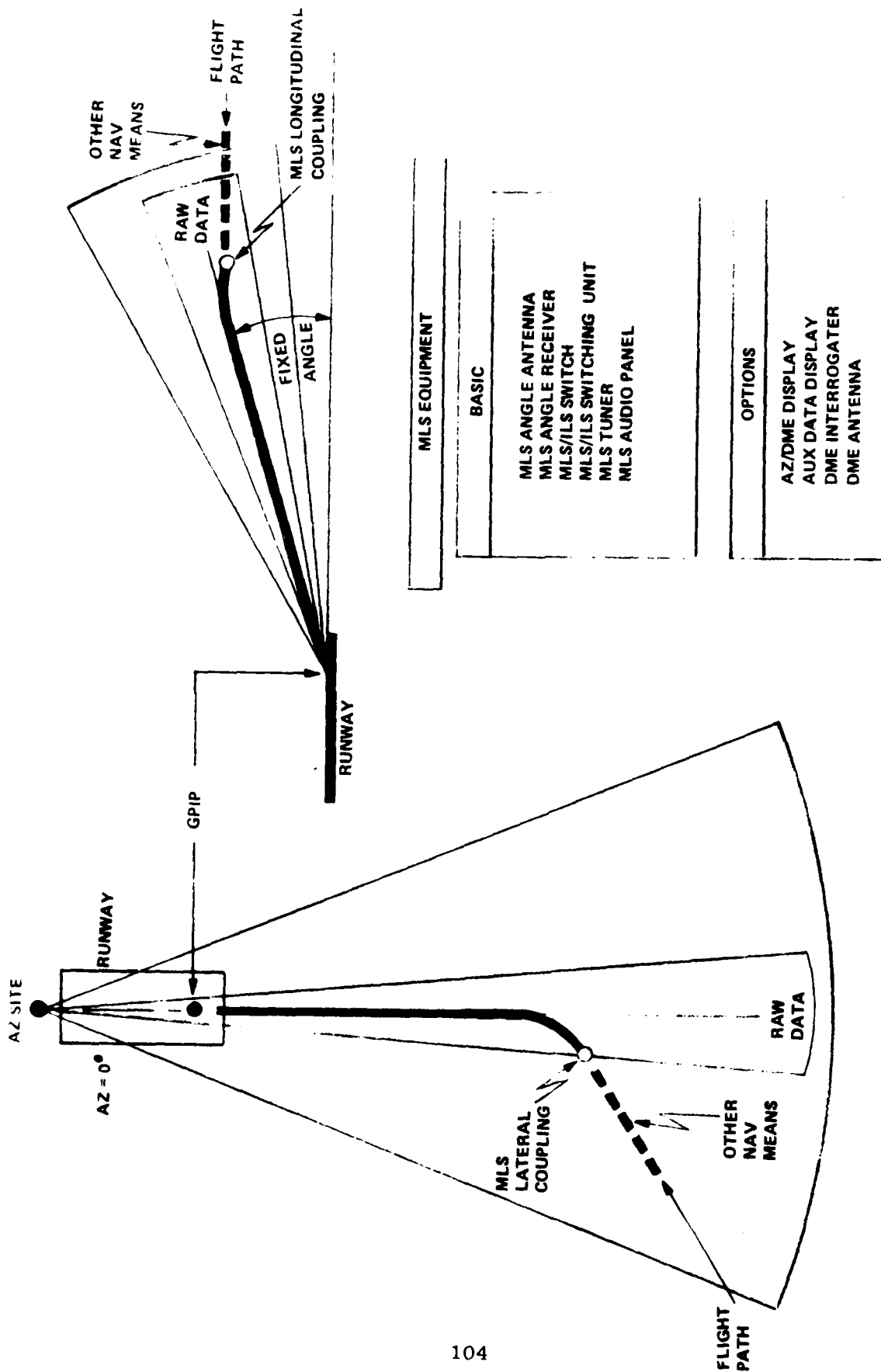


Figure 35 MLS-1 Configuration Direct ILS Replacement

fixed selection capability should be incorporated in the angle receiver such that several ship's wires will key a standard receiver to this configuration. A typical MLS-1 configuration tuner is illustrated in Figure 36.

Except for the channel tuning and MLS selection (MLS/ILS switch), the operational MLS procedures for this configuration are the same as those for the ILS system. The aircraft is maneuvered to the desired beam intercept angle using other navigation means, the runway heading is selected on the HSI course pointer (for autopilot and flight director computations), and the present autopilot and/or flight director ILS mode is then activated. Since the MLS interface in this configuration is identical to that of ILS, the flight control system and cockpit displays behave as if the ILS mode is engaged.

To realize a significant advantage of MLS, the DME function can be added to this configuration as an option. The DME interrogator outputs can be switched to the existing range readouts as a function of selecting the MLS mode. If the range readout device is an analog interface (commonly 3 synchros to drive 3 digit wheels), an analog to digital converter must be installed. As an alternate a digital MLS DME, or AZ/DME, display can be added (see Figure 37) which is compatible with the digital outputs of the DME and angle receivers, thus providing indications of the full azimuth and DME coverage.

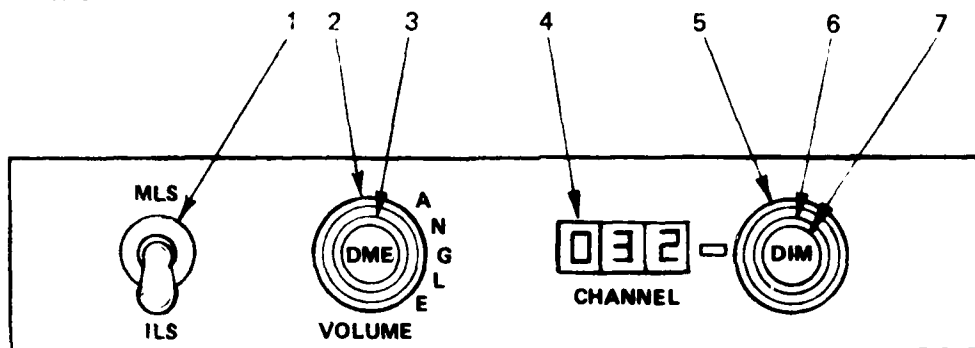
A block diagram of the MLS-1 (and MLS-2) configuration appears in Figure 38. Components of the existing system are on the right of the illustration. All others are MLS additions, and the dashed components are MLS options.

Figure 39 is an illustration of a typical MLS Auxiliary Data display. This unit was built by Bendix Avionics Division as part of the Phase III MLS airborne equipment package. As noted in the figure, it allows presentation of only a few of the many auxiliary data parameters discussed in Section 3.4 of this report.

4.1.2.2 MLS-2 Selectable Azimuth and Elevation Configuration

This configuration is a minor modification of the basic MLS-1 system and is, in fact, the system provided as part

1.125" X 5.75"



1. MLS/ILS SWITCH SELECTS EITHER MLS OR ILS APPROACH MODE.
2. CONTROLS VOLUME OF MLS ANGLE RECEIVER AUDIO CODE.
3. CONTROLS VOLUME OF DME INTERROGATOR AUDIO CODE.
4. DISPLAYS MLS CHANNEL SELECTED
5. CONTROLS HUNDRED (0-2) AND TENS DIGITS OF DISPLAY.
6. CONTROLS UNITS DIGIT OF DISPLAY
7. DIMS DISPLAY

Figure 38 Typical MLS-1 Tuner

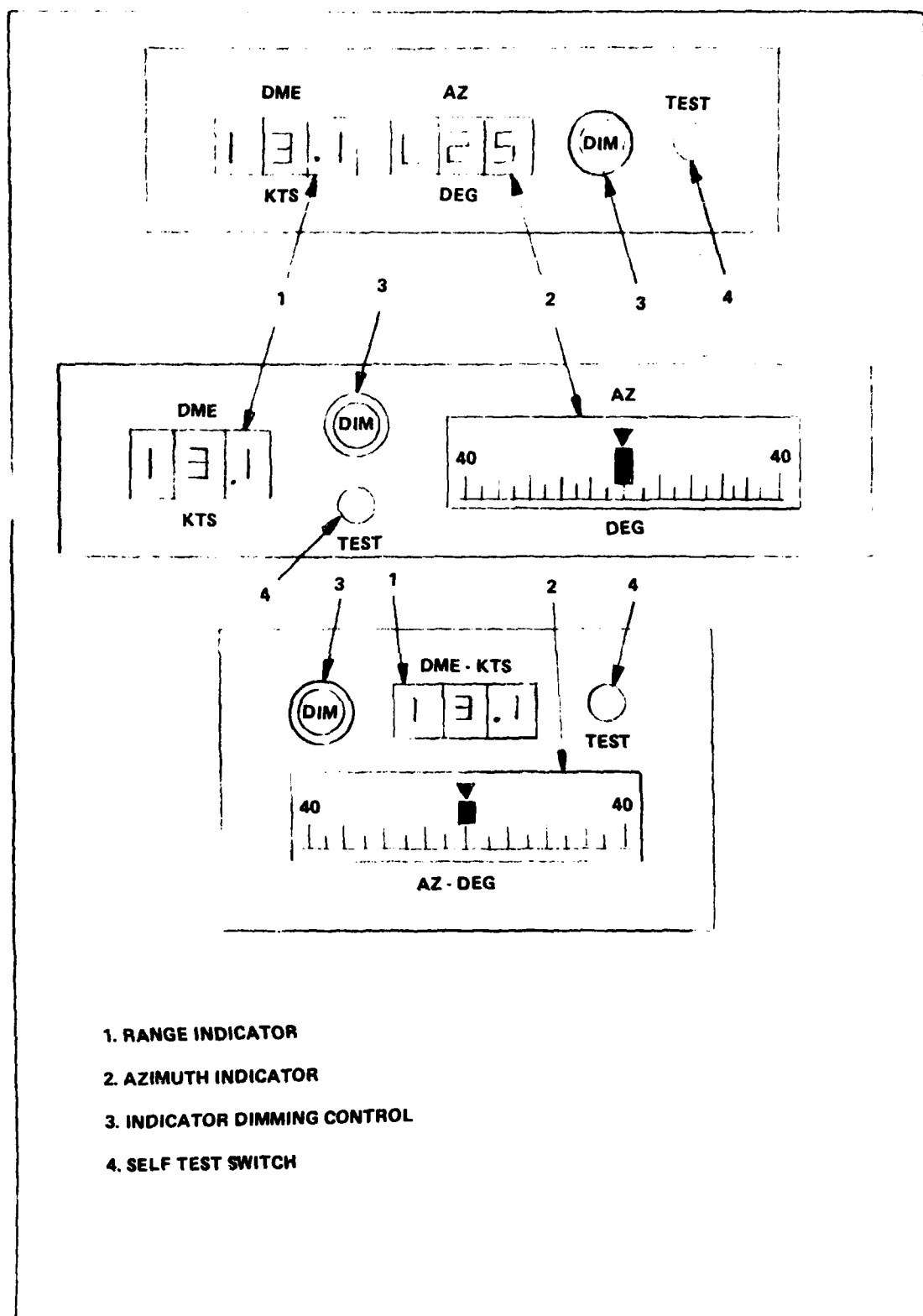


Figure 37 Typical Azimuth/DME Indicators

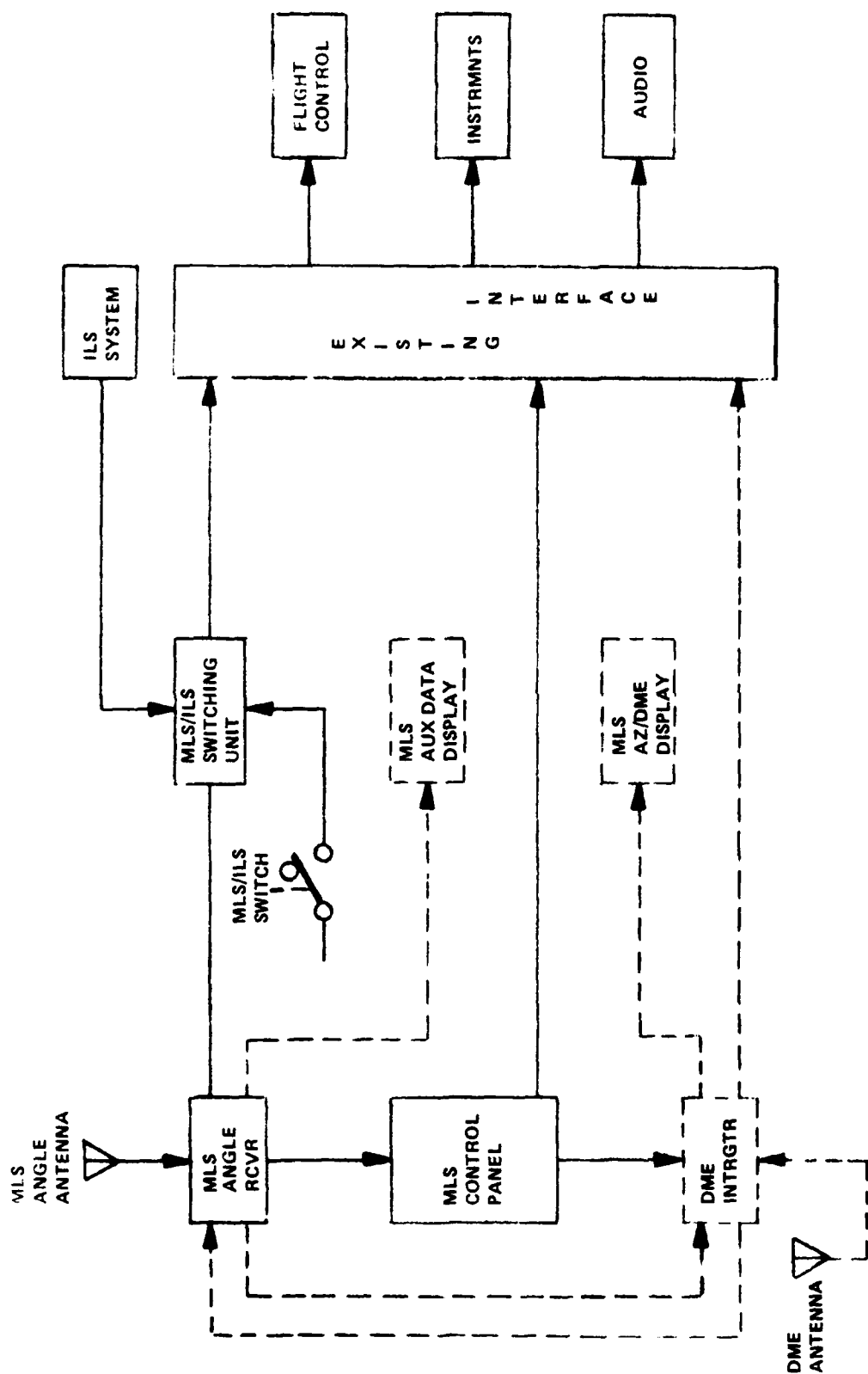
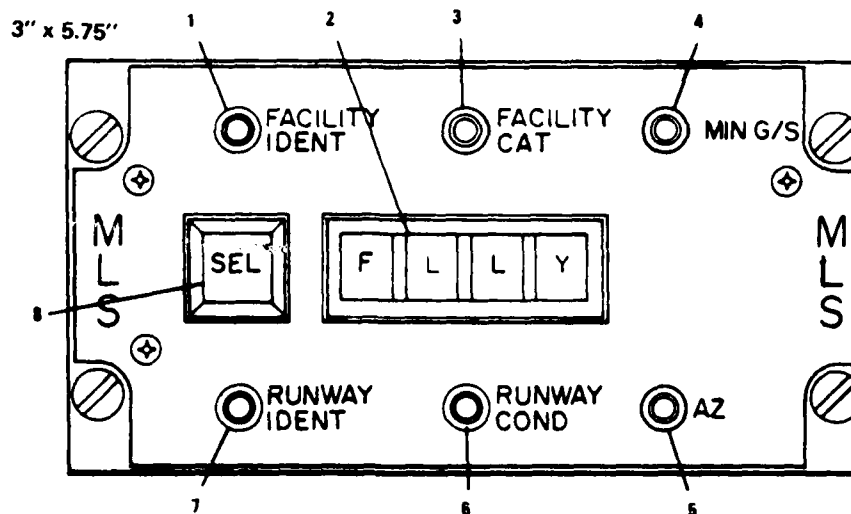


Figure 38 Block Diagram MLS-1 & MLS-2 Configurations
(Direct ILS Replacement & Selectable Azimuth & Elevation)



NO.	FUNCTION
1	When pressed selects the FACILITY IDENT function for display when SEL is pressed. The display appears in the framed area to the right of SEL (item 2). The display is a three-letter combination such as IDL or FTL etc.
2	The display area for the various selected functions. The display may be a combination of letters and/or numbers when pressing SEL. Display disappears after a few seconds or after another function is selected.
3	When pressed selects the FACILITY CAT (category) function for display when SEL is pressed. Display is I, II or III. These categories relate to weather-handling capabilities of the ground facility. The using aircraft must have the proper equipment to comply with the conditions existing.
4	When pressed selects the MIN/GS (minimum glide slope) function available at that facility when SEL is pressed. Display will be in degrees. First digit can be either 0 or 1, second digit 0 to 9 and third digit .0 or .5.
5	When pressed selects AZIMUTH function for display when SEL is pressed. The display is initially L or R followed by two digits. This figure is the number of degrees the aircraft is L (left) or R (right) of the runway centerline. As aircraft approaches the centerline, this reading decreases numerically to 00.
6	When pressed selects the RUNWAY COND (condition) function for display when SEL is pressed. Display is WET, ICE etc.
7	When pressed selects the RUNWAY IDENT function for display when SEL is pressed. Display is a two digit runway heading with L (left) or R (right) direction indicator such as 15L or 15R and 33L or 33R etc.
8	When pressed selects each of the above functions for display.

Figure 39 Typical MLS Auxiliary Data Display

of Phase III MLS. The same basic MLS-1 equipment is required; however, a tuner/selector must be substituted for the MLS-1 tuner. The required equipment and approach considerations are illustrated in Figure 40. A typical MLS-2 tuner/selector is illustrated in Figure 41.

Although this configuration is more versatile than MLS-1, it is not recommended for CTOL or STOL aircraft because of the obvious operational limitations involved in approaching a runway along a radial not aligned with the runway centerline. To take advantage of the desirable capability of selecting a non-standard glide slope, especially for STOL aircraft, a configuration allowing only this selection is more practical for USAF mission requirements. Since this last configuration is just a simplification to the more general MLS-2 configuration, it will not be covered in any more detail.

To utilize the MLS-1 configuration, the MLS/ILS switch on the tuner/selector is placed in the MLS position; the appropriate channel, azimuth and elevation (GS) angles are selected; and the magnetic heading of the desired azimuth is selected on the HSI course pointer (for flight director and/or autopilot coupler computations). The ILS mode is then activated, and the system behaves as if the ILS mode is engaged with an azimuth reference that need not be zero. If a 0 degree azimuth has been selected, the lateral axis capabilities are identical with the MLS-1 configuration and with ILS. As in MLS-1, the analog raw deviation outputs from the MLS angle receiver are applied directly to the existing couplers and instrumentation. The deviations are referenced to the selected angles and no new computer is required.

The operational limitation of this configuration is that if an azimuth angle other than zero is selected, the referenced flight path is not coincident with the center of the runway. At some point in the approach, at an altitude much higher than the Category I limit (200 feet), the pilot must decouple the MLS system and, using visual ground cues, align the aircraft with the runway. For azimuth angles other than zero, this configuration is not capable of Category I system performance for low approaches during limited weather conditions.

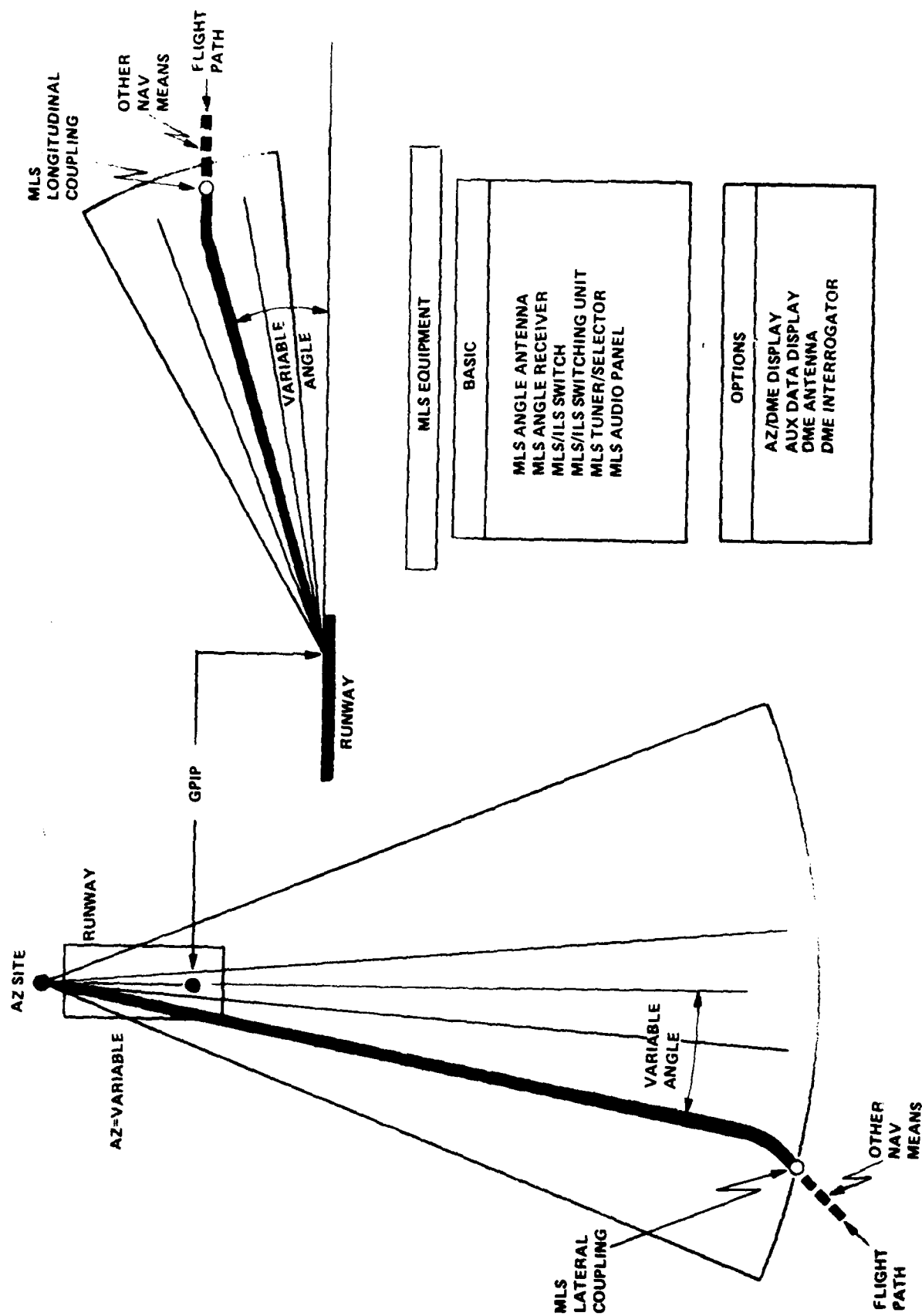
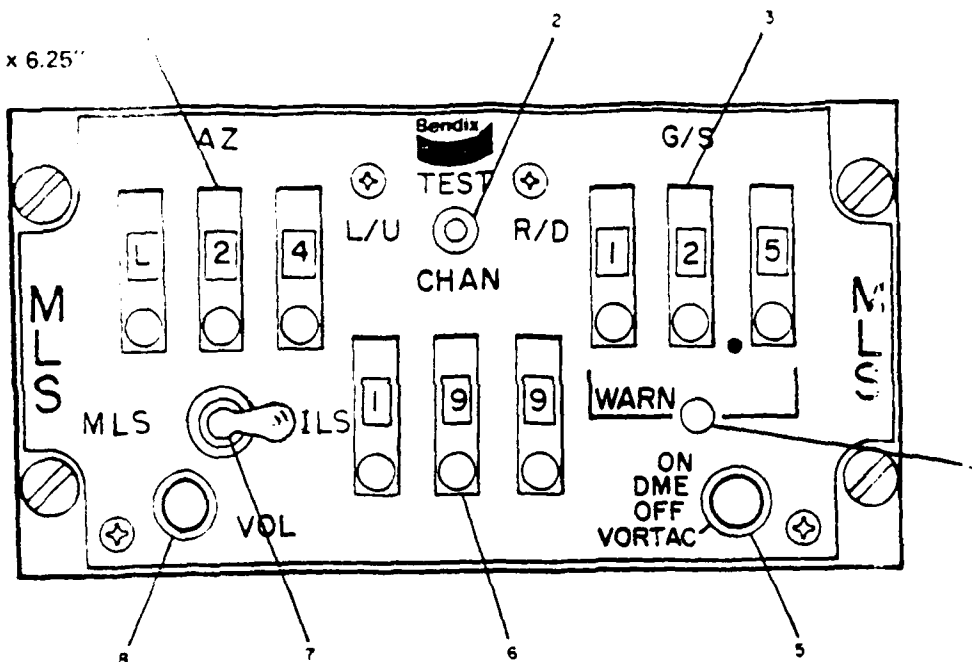


Figure 40 MLS-2 Configuration Selectable Azimuth & Elevation

5.75" x 6.25"



NO.	FUNCTION
1	These three pushbutton digital switches select the azimuth radial used to compute azimuth angle deviation. They range from L00 to L49 and R00 to R49 in one degree increments. Only angles between L40 and R40 are usable. Angles that exceed this range are converted to either L40 or R40. L/R means left or right.
2	Test junction that generates a L/U (left/up) or R/D (right/down) indicator deflection on the CDI.
3	These three pushbutton digital switches select the glide slope used to compute elevation angle deviation. They range from 00.0 to 10.5 degrees in increments of 0.5 degrees. Only angles between 2 and 15.5 are usable. Angles exceeding this range are converted to either 2 or 15.5 degrees.
4	If a glide slope is selected that is below 2° or the minimum selectable or greater than 15.5°, or if azimuth is selected that is greater in magnitude than $\pm 40^\circ$.
5	This switch in VORTAC sets the DME in a standard operating mode. VORTAC removes all power to the Angle Receiver. DME OFF reserved for future use. On applies power to Angle Receiver and transfers the DME from the VORTAC mode to a precision approach MLS mode.
6	These three pushbutton digital switches select the channel that the MLS angle receiver is on. Their range is from 000-199 dedicated to commercial channels. These are coded in standard 2 of 5 coding.
7	This switch selects either the MLS or ILS approach system.
8	This 500 ohm potentiometer adjusts the audio volume of the morse code (station identification).

Figure 41 Typical MLS Control/Display Unit

Figure 38 is a block diagram of the MLS-2 configuration. The DME function is again noted as optional, and its considerations are the same as for the MLS-1 configuration. DME is recommended to provide increased progress and situation information, especially if marker beacons are not provided at all desired landing sites.

4.1.2.3 MLS-3 Selectable Intercept of Final Configuration

This configuration is the basic MLS-1 system with: a tuner/selector substituted for the tuner; DME equipment; and an MLS navigation coupler. Operationally, this configuration permits selection of intercept angles (lateral and longitudinal) to the final approach via a simple, fast selection process. The required equipment and approach considerations are illustrated in Figure 42. A typical MLS-3 tuner/selector is illustrated in Figure 43.

The MLS navigation coupler required for this configuration accepts the digital outputs from the angle receiver and DME interrogator. These outputs are processed by the coupler in conjunction with the selected lateral and longitudinal intercept data to provide computed deviation and situation information to the flight controls and instruments. At some point in time soon after the transition to the final approach, MLS raw deviation data (equivalent to ILS data) is coupled to the flight controls and instruments. For this configuration, the final approach azimuth angle (0 degrees) and elevation angle are set to field nominal values via aircraft wiring. They are not selectable by the pilot.

Referring to Figure 43, the MLS approach set-up procedure is as follows:

- 1) Pilot arms MLS mode by placing MLS/ILS switch (ref.3) to MLS position.
- 2) Select switch (ref. 8) is placed in "CHAN" position, and appropriate channel is selected by manipulation of select knobs (ref. 5 and 6) using display (ref. 4) as visual reference.
- 3) Select switch (ref. 8) is then placed in "HDG" position, and select knobs (ref. 5 and 6) are manipulated to adjust to the desired intercept heading.

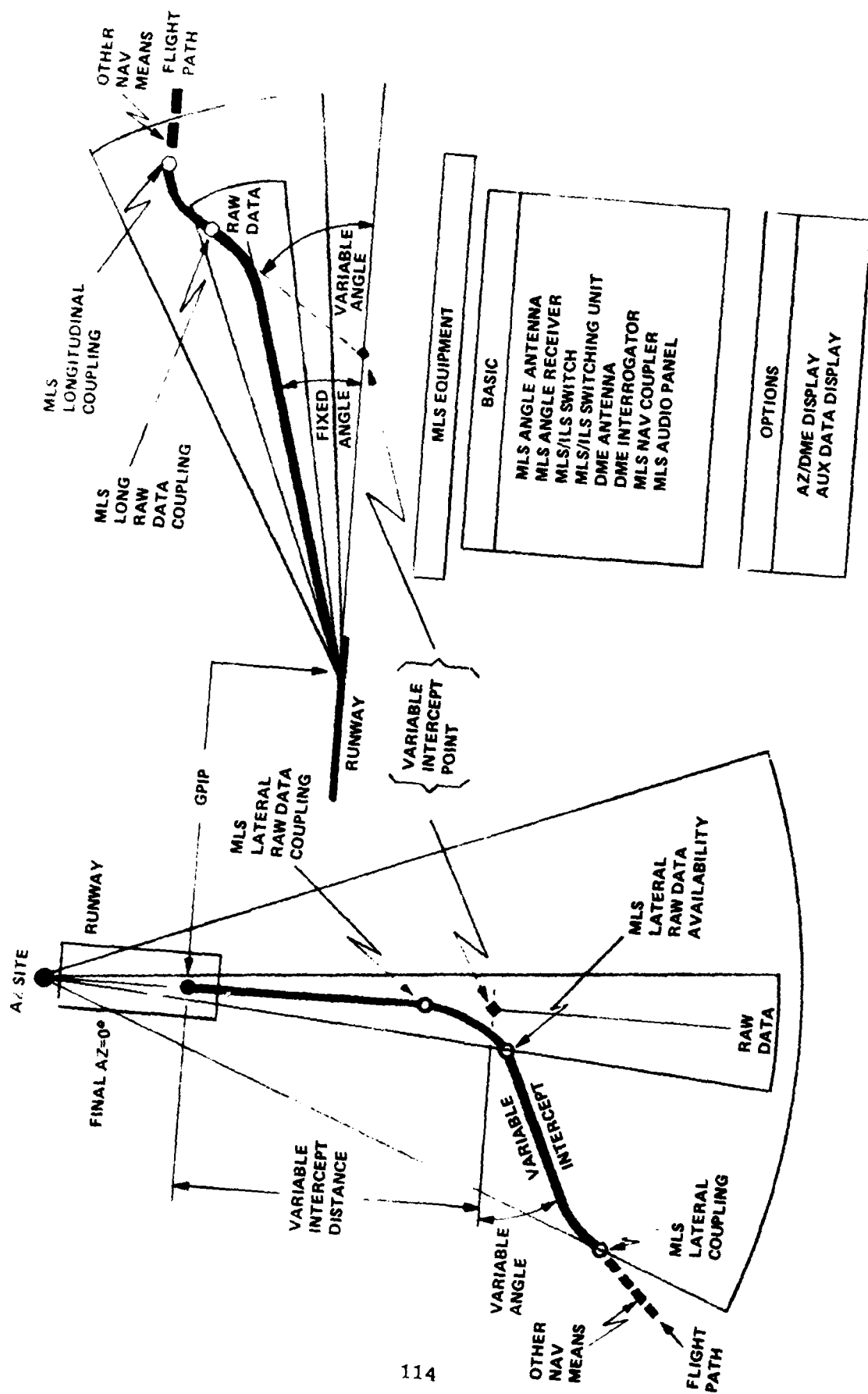
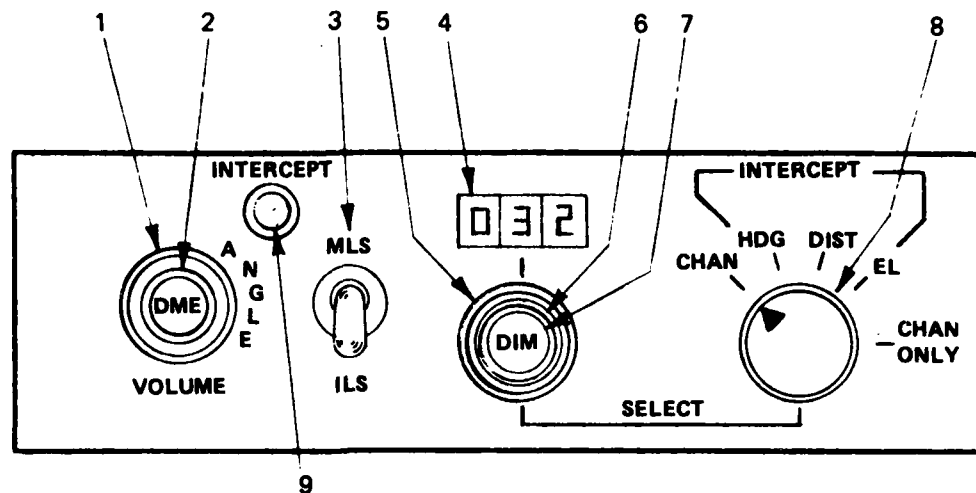


Figure 42 MLS-3 Configuration Selectable Intercept Of Final

5.75" X 1.75"



1. CONTROLS VOLUME AT MLS ANGLE RECEIVER AUDIO CODE.
2. CONTROLS VOLUME OF DME INTERROGATOR AUDIO CODE.
3. MLS/ILS SWITCH SELECTS EITHER MLS OR ILS APPROACH MODE.
4. DISPLAYS NUMERICAL VALUE OF FUNCTION SELECTED BY SELECT SWITCH.
5. CONTROLS HUNDREDS AND TENS DIGITS OF DISPLAY
6. CONTROLS UNITS DIGIT OF DISPLAY
7. DIMS DISPLAY
8. SELECTS FUNCTION TO BE DISPLAYED OR BASIC ILS TYPE APPROACH (CHAN ONLY SELECTED)
9. LIGHT WHICH ILLUMINATES WHEN MLS INTERCEPTS MODE IS ENGAGED. NOT LIT ON FINAL.

Figure 43 Typical MLS-3 Tuner/Selector

(Note: Runway heading is part of ground site-transmitted data).

- 4) Select switch is then moved to "DIST" position and the variable intercept distance in nautical miles (see Figure 42) to the GPIP is selected.
- 5) Select switch is then moved to "GS" position, and the longitudinal intercept angle to the final is selected.
- 6) If a "straight-in" approach (no intercept) is desired, the select switch (ref. 8) is placed in the "CHAN ONLY" position, and only the channel must be selected. The system will then behave as the direct ILS replacement (MLS-1).

A block diagram of the MLS-3 configuration is illustrated in Figure 44. Options include the MLS AZ/DME and Auxiliary data displays.

Operational capabilities of the MLS-2 configuration are available by: setting the "HDG" to the desired intercept heading; setting the "GS" to the desired elevation angle; and setting the "DIST" to a 0.0 nautical mile intercept offset distance.

To safely perform to this level of MLS capability during IFR conditions, automatic control may be necessary (especially for single-seat aircraft) to make pilot workload acceptable. This requires further study in the simulation phase. The display requirements for the MLS-3 configuration include the means to monitor approach progress and maintain situation orientation while on the final approach intercept segment. It is felt that this can definitely be accomplished using the conventional electro-mechanical navigational instrumentation found on all present-day USAF aircraft because the MLS intercept is merely a precise ILS intercept.

With ILS, the pilot is vectored by ATC to a heading which will intercept the localizer beam. Due to beam width and bank angle constraints, localizer capture normally occurs 7 to 10 nm from the runway threshold. During the intercept prior to capture the pilot is following the compass card on the HSI, or is in a coupled autopilot or flight director heading mode. The CDI and course pointer information on the HSI provide him with his angle of

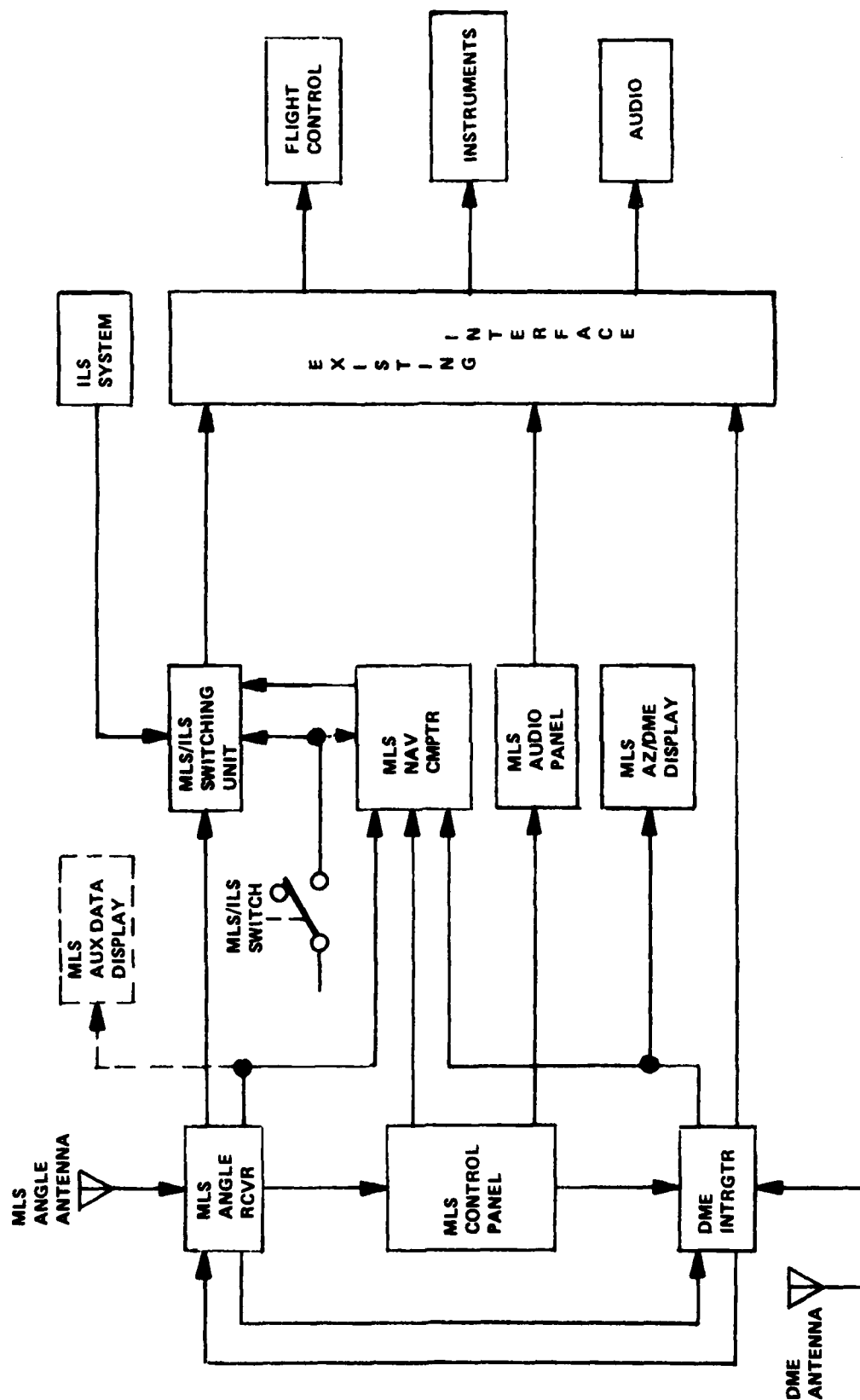


Figure 44 Block Diagram MLS-3 Configuration (Selectable Intercept)

intercept only. He cannot easily tell where he is in relation to his localizer capture point because his CDI is "pegged" to one side of the case. He also has no means of flying an accurate ground track during this intercept leg.

With the MLS-3 configuration, the MLS navigation coupler calculates a specific ground track from the pilot-entered data and outputs data to the navigation displays as shown in Figure 45. Deviation information, calculated about the ground track, is displayed on the CDI (lateral deviation): the course pointer is automatically rotated to the intercept heading (desired track angle); the heading marker is rotated to the runway heading (path anticipator); the bearing pointer is rotated according to the relative bearing of the aircraft with respect to the azimuth site; and, the DME wheels are positioned as a function of the range to the final approach transition point. In addition, it is recommended that an AZ/DME display be provided to allow MLS digital raw data monitoring and manual control on a third approach segment.

Since the navigational coupler in use with this configuration utilizes the full coverage MLS data, routinely successful final approach captures can be achieved less than 2 nm from the runway threshold. Because existing autopilot and flight director ILS control law gains are normally optimized for captures at longer ranges, it is recommended that the MLS coupler remain coupled until the capture is complete and the aircraft is tracking the final segment. Switchover to the existing ILS control laws can then occur without oscillatory performance. The actual implementation of this logic operation and MLS control through the autopilot/flight director computers requires a very detailed investigation of the computer hardware for each specific aircraft. Although the final result of such an investigation will probably result in a fairly simple modification to the autopilot/flight director computers (as discovered in Reference 21), further analysis of this issue was not within the scope of this study.

Control-and-display requirements in the vertical axis are effectively identical to those in the lateral axis. On the initial descent leg the MLS coupler calculates deviation with respect to the desired flight path defined by the pilot in terms of the final approach length and the initial

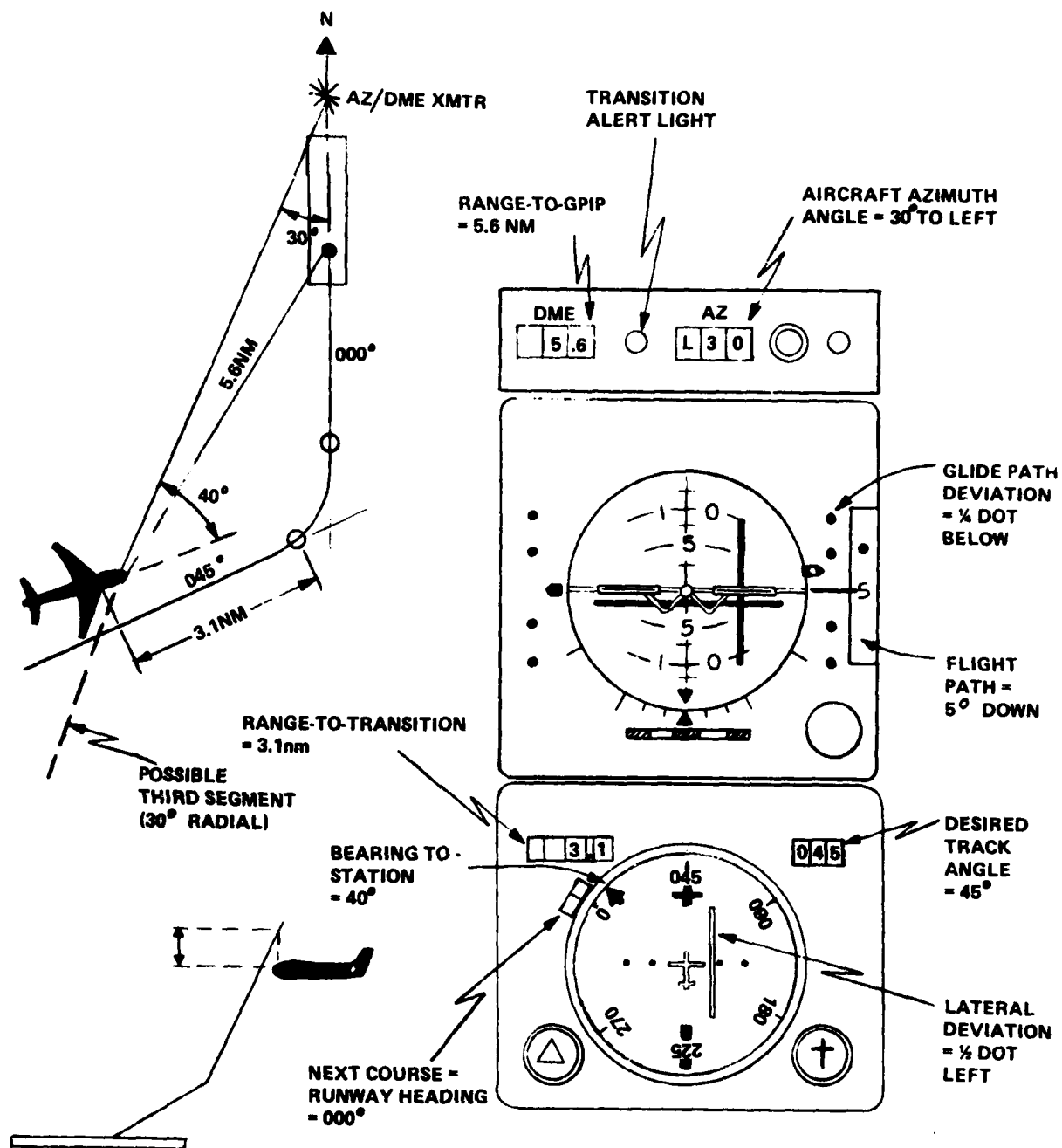


Figure 45 MLS-3 Displays

descent flight path angle. This deviation information is displayed on the GSI and utilized for control. Approach progress monitoring is provided by his altitude indicators, rate-of-climb indicator, MLS range-to-transition indicator on the HSI, and the range-to-station indication on the AZ/DME display. As for the lateral control, it is recommended that the MLS coupler remain coupled to perform the transition to the final descent angle.

4.1.2.4 MLS-4 Complex Trajectory Configuration

This configuration is the most sophisticated and permits selection of complex lateral and longitudinal approach paths. A control and display unit (CDU) and an MLS navigation computer are substituted for the tuner/selector and navigation coupler of the MLS-3 configuration. The required equipment and approach considerations are illustrated in Figure 46. A typical CDU appears in Figure 47. Detailed discussions on this CDU and other candidate units are contained in Section 4.3.

Like the MLS-3 configuration, digitally formatted information from the DME interrogator and angle receiver is utilized, in conjunction with the desired trajectory data, to provide computed deviation and situation information to the flight controls and instruments. The desired complex trajectory approach path is entered into the navigation computer via the CDU. Other functions absorbed by this unit include channel selection, antenna selection, and all of the display functions of the MLS auxiliary data display. An automatic data entry unit is indicated on the MLS-4 configuration block diagram, shown in Figure 48 as an option. This unit, if required, permits rapid entry of complex trajectory definition data.

As discussed in other areas of this report, the display requirements for complex trajectory flight must provide the pilot with sufficient clear information to allow him to control his aircraft, monitor his approach progress, and maintain orientation with respect to his desired path and the runway. Moreover, this must be done in an integrated manner to result in acceptable levels of pilot workload.

Flight test results from the T-39 program have indicated that a pilot cannot perform the control function, even via

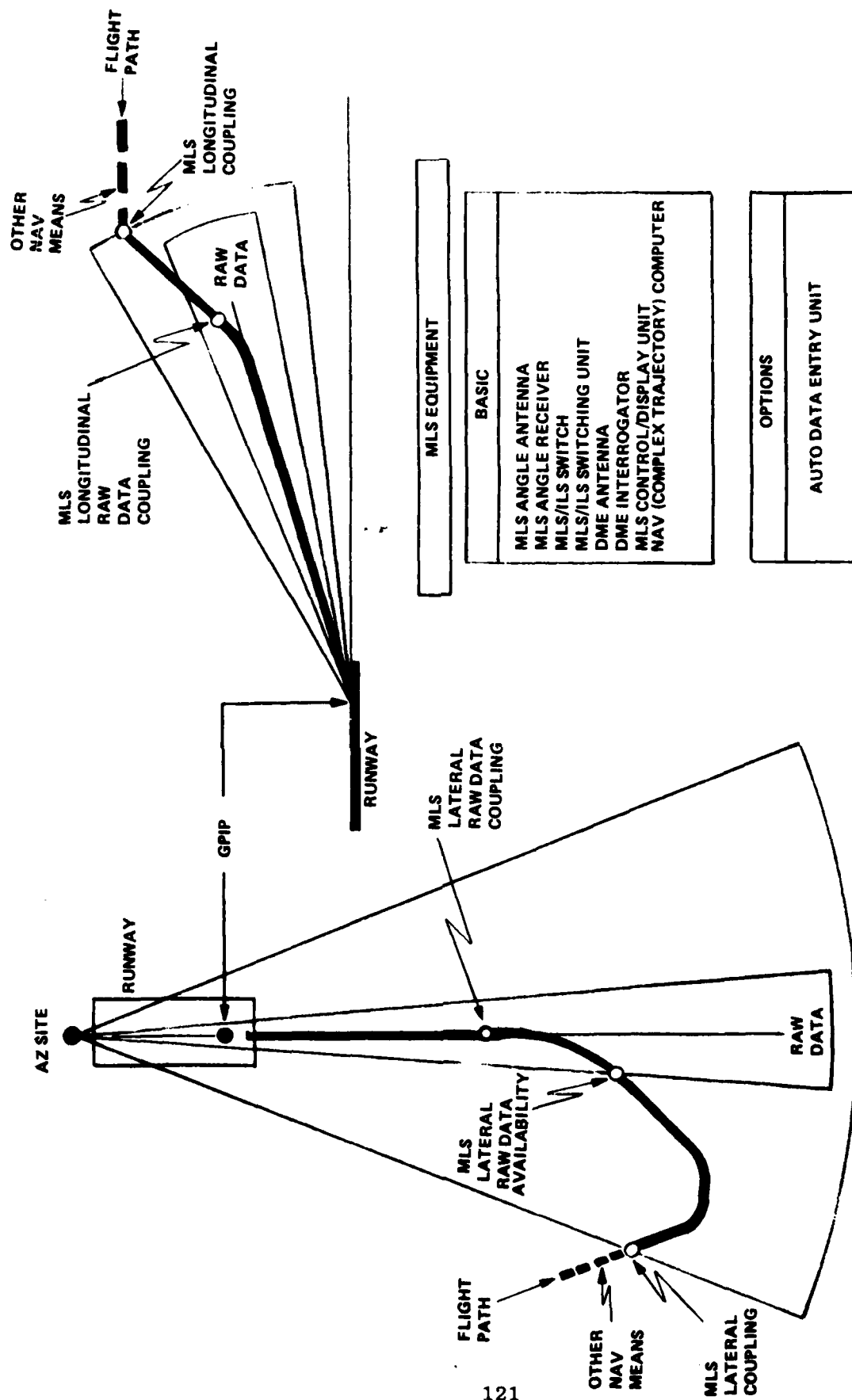


Figure 46 MLS-4 Configuration Complex Trajectory

5.75" x 6.25"

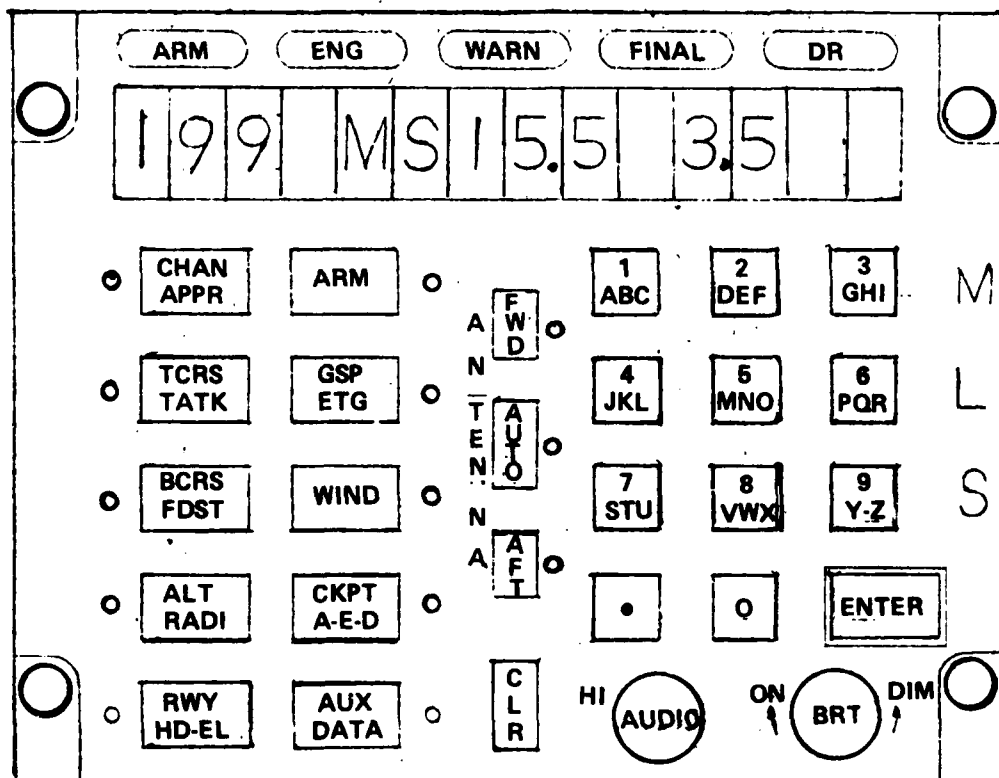


Figure 47 Typical MLS Control/Display Unit

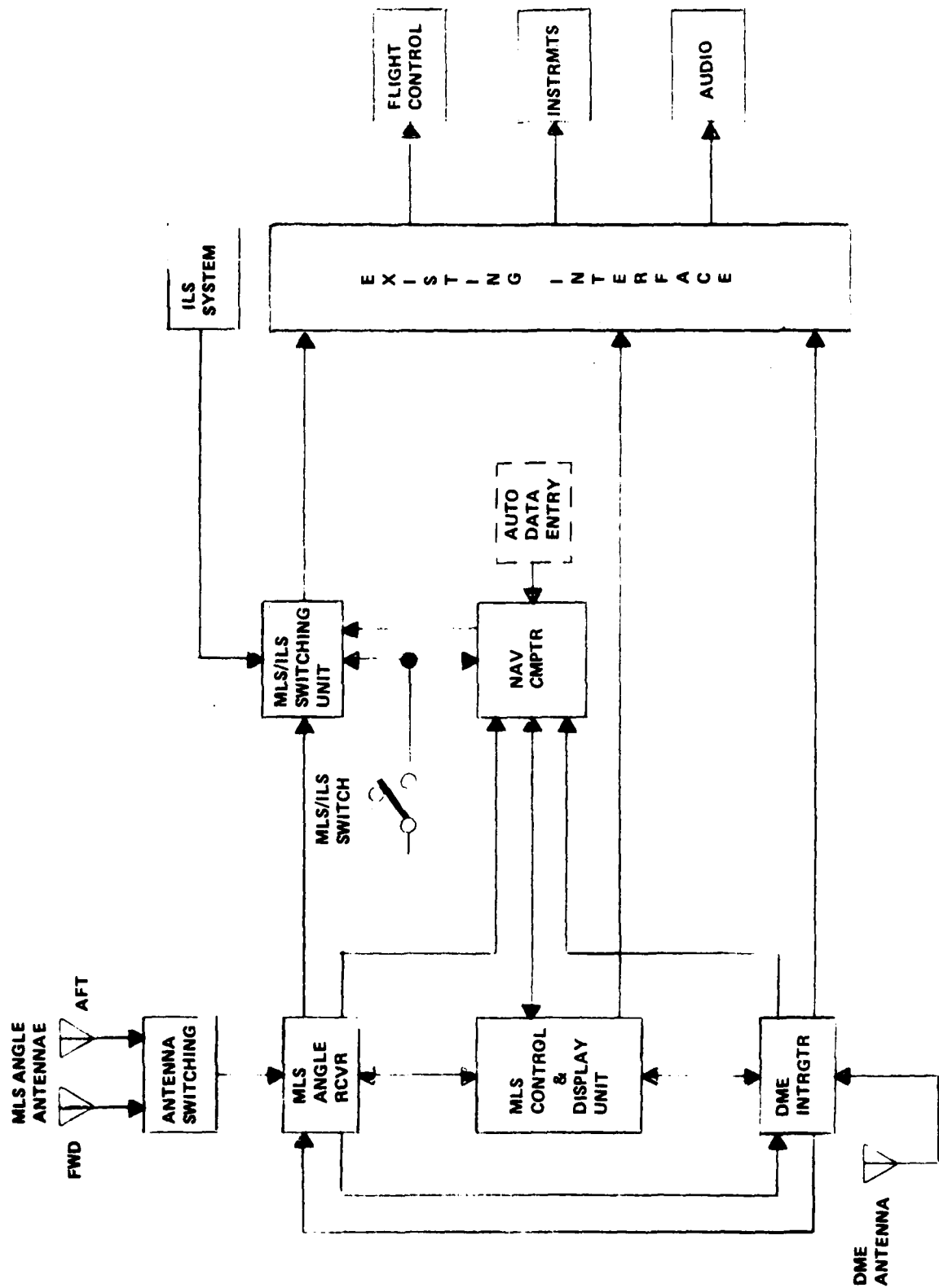


Figure 48 Block Diagram MLS-4 Configuration (Complex Trajectory)

the flight director, and still adequately monitor the complex approach and continuously assess his rapidly changing situation with present electro-mechanical instrumentation. Performance of this task is even doubtful when the aircraft is under automatic control. For this reason, Section 4.2 has been dedicated to defining candidate complex trajectory flight display presentation for a state-of-the-art electronic color CRT indicator.

Attempts to improve the electromechanical instrumentation for complex trajectory flight should continue, however, for the simple reason that the vast majority of present-day aircraft contain only this type of equipment. To expect that fleets of aircraft will be modified to add new electronic navigational instruments and their associated symbol generation computer hardware appears to be quite unreasonable. For this reason, a minor modification to the display scheme discussed previously for the MLS-3 configuration (see Figure 45) should also be considered as a candidate for complex trajectory flight. This scheme involves displaying the following parameters on the following instrumentation:

- Desired track angle -- On HSI course pointer. The MLS navigation computer automatically slews the pointer to the course of the lateral segment. It smoothly rotates about the prescribed circular arc during the transition from one lateral segment to another.
- Lateral deviation from desired track -- On HSI course deviation indicator. The MLS navigation computer drives the CDI during the complex portion of the approach and the MLS angle receiver drives it during the final approach segment.
- Range-along-track-to-GPIP -- On HSI DME readout. The MLS navigation computer drives the readout based on the distance from the aircraft to the touchdown point assuming the aircraft flies along the selected path.
- Relative bearing-to-station -- On HSI or RMI bearing pointer. The MLS navigation computer drives the pointer to indicate the aircraft's

bearing to the azimuth ground transmitter.

- Path anticipator -- On HSI preset heading marker. The MLS navigation computer automatically slews the marker to the magnetic course of the next lateral segment.
- Vertical deviation from desired glide path -- On ADI (or HSI) glide slope indicator. The MLS navigation computer drives the GSI during the complex portion of the approach and the MLS angle receiver drives it during the final approach segment.
- Flight path angle -- On ADI flight path angle scale, if one exists. Although not essential if the existing cockpit does not contain a suitable display of this parameter, it is especially useful during multi-segmented descents. It is driven from the MLS navigation computer.
- Azimuth angle and range-to-GPIP -- On the MLS AZ/DME indicator. The AZ/DME display is driven directly from the MLS angle receiver and thus presents a continuous readout of raw data information throughout the approach.
- Transition alert -- On the MLS AZ/DME indicator. This shall be provided in the form of an amber light which shall flash for approximately 15 seconds to alert the pilot of an upcoming segment transition. It shall be driven from the MLS navigation computer.

4.1.3 Miscellaneous Interface Requirements

Certain aircraft may require special interface units when MLS is incorporated. These units are as follows:

- AC-DC Converter -- This unit is required only if inadequate DC or no DC is available for the MLS system.
- Digital/analog converter -- This unit is required

to interface digital range data to analog-controlled displays if a navigation coupler or computer is not provided.

- Remote RF Head -- This unit transforms the microwave frequencies to L-band prior to subjecting the signal to long cable runs. This allows use of relatively inexpensive flexible coaxial cable with acceptable line loss. For small aircraft not requiring long cable runs, an RF head integral to the receiver eliminates the need for this unit. Large aircraft configured for the MLS-3 and MLS-4 configurations are the only candidates for this unit since they may require front and aft antennas.
- Antenna Switching Unit -- This unit is required for aircraft which use fore and aft antennas to maintain signal coverage during complex trajectory flight. Without this unit, antenna "masking" during turns can result in invalid data for significant periods of time (typically 10 seconds for T-39 approaches). This results in a dead-reckoning mode and a consequent degradation in control accuracy.

4.1.4 Considerations Regarding Replacement of Existing Equipment

Certain aircraft utilize flight director and/or autopilot couplers which may not be adequate for MLS flight path control. These should be replaced with updated units if MLS is incorporated. An example is the autopilot installed aboard the C-130 aircraft. Presently, the operational manual for this aircraft recommends either not using or closely monitoring the autopilot below 1000 feet. If this system is left intact, incorporation of a complex MLS system is not justifiable.

If, in a particular aircraft, an MLS system is required and cockpit space is not available for adding MLS components (particularly displays), equipment may be substituted which is compatible with the MLS and existing systems. If certain existing instruments do not have provisions to

accept required MLS information, and other instruments in the USAF inventory do, then a substitution may be recommended. An HSI with a remotely-sleuable course pointer for display of complex trajectory situation is an example of a unit which falls in this category.

4.1.5 Mode Annunciation and Logic Switching Considerations

As part of the pilot's display information during coupled approaches, most aircraft installations provide means to annunciate the associated ILS modes. Examples are : LOC, LOC ARM, LOC ENG, LOC TRK, GS, GS ARM, GS ENG, and GS TRK. In general, the annunciations are controlled by logic generated in the couplers (autopilot or flight director) which utilize raw data in conjunction with other data to switch from one submode to another (e.g., LOC ARM to LOC ENG). Since a straight-in MLS approach is equivalent to an ILS approach, no change in the label of these annunciations is contemplated for an MLS retrofit. Although it may be argued from a human factors standpoint that ILS mnemonics is certainly not the ideal annunciation for MLS flight, it is felt that its use would be acceptable to minimize retrofit costs if no safety of flight problem is created.

Pilot selection of an MLS approach versus an ILS approach is different in that for MLS he selects a channel and for ILS tunes a frequency. It would be very unlikely for the pilot to mistake one procedure for the other. For aircraft installations which include both MLS and ILS, the second part of the pilot procedure in selecting an MLS straight-in approach is to position the MLS/ILS switch to the MLS position. Failure to perform this task, however, may not be immediately apparent if no annunciation change is made. Under certain coincidental conditions of a nearby ILS frequency being tuned or an ILS receiver failure, pilot error in not selecting the MLS switch position could result in the pilot mistakenly flying active, or even inactive, ILS data instead of MLS data. This could definitely compromise safety of flight.

Due to the above argument, it is felt that some form of MLS annunciation is required. As an alternate to all new annunciation mnemonics, a small light can be installed on the instrument panel to indicate the selection of MLS.

For the four MLS configurations, the final approach utilizes raw MLS deviation data for control and for existing coupler logic to control annunciations. The MLS-3 and MLS-4 configurations utilize navigation couplers and computers, respectively, to control the flight path prior to final. The normal ILS logic within the existing couplers will be armed when the MLS approach mode is selected. When the aircraft is controlled via the MLS navigation coupler or computer within the levels of the existing ILS threshold logic, the existing ILS coupler will automatically engage and consequently cause the MLS coupler to disengage.

MLS annunciations prior to final are accommodated by the CDU (see Figure 47, top of panel) for the MLS-4 system. In the MLS-3 system, a light is provided on the tuner/selector (Figure 43, ref. 9) to annunciate that the intercept mode is active. Logic is provided by the MLS navigation coupler to illuminate the light when the MLS mode is first selected and to extinguish it when the final is engaged.

4.2 Electronic Display Candidate Configurations

Presenting information to the pilot in a coordinated, readily interpreted format while exploiting the full capabilities of the MLS system requires a display medium having flexibility and capacity beyond that possible with electro-mechanical indicators. The CRT currently is the most logical candidate although LED and/or LCD matrix panels may replace the CRT in the future. The proposed display concepts would apply in any case. Use of a programmable color CRT display will provide an avenue to easily evaluate numerous variations of display parameters leading toward an optimum combination. A description of 2-D and 3-D displays are included herein and these displays are proposed as candidates for further evaluation.

4.2.1 Implications of the Shift from Electromechanical to Electronic Displays

The shift from electromechanical displays to electronic displays for primary command, control, performance, and navigation information constitutes a potential for a quantum jump in the effectiveness of cockpit displays as a result of the following:

- It is possible to present much more information on electronic displays.

- There is much more freedom for the display designer, particularly in the opportunity to associate a number of display elements moving with respect to each other.

It is important in this shift to have the early generations of electronic displays be designed as well as possible. Traditions and expectancies form rapidly and later modifications in design principles may be difficult to accomplish.

There are some characteristics inherent in electromechanical flight display design which can carry over to limit or distort what might be done with electronic displays. Two of these are:

- The erroneous assumption that we have been pushing the limit in the amount of information which can be processed by a pilot.
- The erroneous assumption that the pilot's task can be simplified by reducing the amount of information displayed to him.

The first assumption is erroneous in that it applies only to electromechanical displays as we have known them. By the use of advanced pictorial quality, the speed with which a pilot can derive information from a display can be increased enormously.

The second assumption is based on a misinterpretation of the pilot's task. Figure 49 shows a diagrammatic representation of the pilot's task in terms of information flow. The left half of the diagram shows information which must be processed by the pilot in flying an aircraft. By providing a display allowing him to assimilate each of the parameters on that left side, his task is relatively simple. If any of those parameters is not displayed, the pilot's task is made more complicated since he must now derive that parameter by mental differentiation, integration, or other relatively complex processes.

In short, the only way to simplify the pilot's task is to provide him all the information he needs and do it in such a way that the information is readily perceived and interpreted. The electronic display can help this process greatly because it provides great design freedom. This design freedom can result in much faster information transfer to the pilot, particularly through allowing a number of display elements to move relative

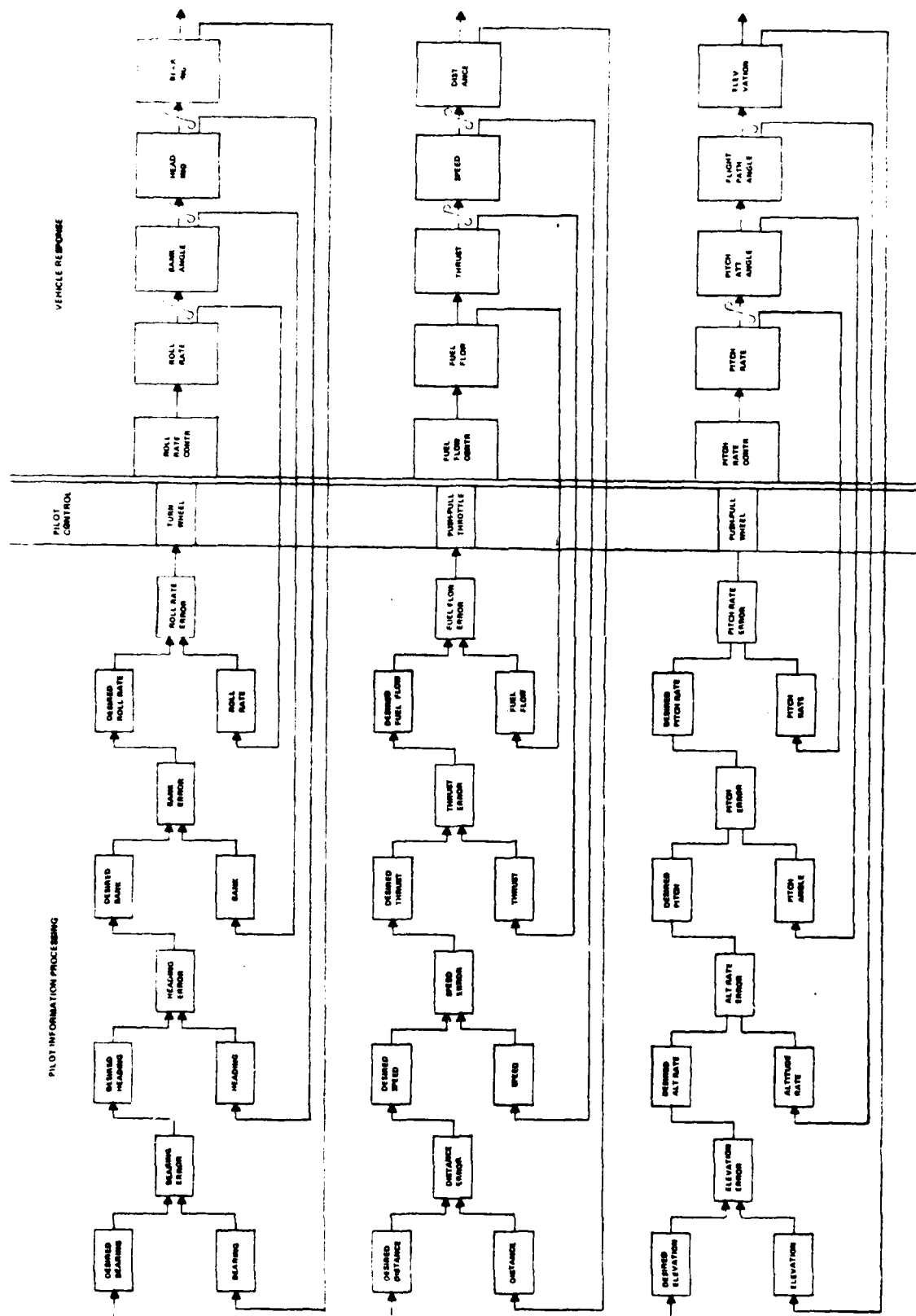


Figure 49 Information Flow Diagram Depicting The Processing Required For Manual Control

to each other in concert.

4.2.2 Baseline Rationale for the Selection of Displayed Parameters for the Electronic Display

The fundamental result of the Microwave Landing System relative to cockpit display systems, is to inform the pilot of his position at any moment in time relative to a specific path in space extending up from the runway on which he intends to land. For information synthesizing purposes it is not nearly enough to provide that data in two dimensions (right-left or up-down). In each of these dimensions he needs to see the trend of relative motion of that line in space and see how his present flight vector relates to that trend. In mechanical display systems the pilot has been forced to derive large portions of situation and control information which has added greatly to his mental workload at just the time when he is in the most critical and dangerous phase of all normal flight operations.

For these reasons the design of the proposed 2D and 3D displays is intended to maximize the pilot's ready interpretation of his situation. That situation is further defined precisely as being the relation of his flight vector in horizontal and vertical dimensions to the vector of his desired path in those same dimensions.

The horizontal relations between actual and desired flight vectors used by the pilot to decide what heading he should fly, and that in turn relative to actual heading, is used to decide what bank angle he needs to achieve or maintain. The display of these parameters needs to be associated in a manner enhancing ready interpretability. For purposes of achieving a path in space it is desirable for the pilot to see desired track angle in addition to heading. Heading should also be considered part of an attitude display, particularly during flight involving large pitch angles.

The vertical relations between actual and desired flight vectors are used by the pilot to decide what flight path angle to fly, and from that to decide on the momentary pitch attitude. The pilot has seldom had flight path angle information available to him in the past and has usually had to approximate it by using a displayed rate of descent.

For each of the control parameters extending from the characteristics of desired path through space back to attitude rate, the pilot must either see or derive three aspects; (1) desired value, (2) actual value, and (3) the direction and magnitude of the difference between them (error). Wherever a display can provide all three, the pilot's workload will be reduced correspondingly.

The third dimension of the pilot's task is the control of velocity, for which he usually uses air speed during an approach. In the interest of having the display help the pilot in his total task, the integration into the display of the information used for this control task will further alleviate the pilot's workload.

It is the thesis of the present design rationale that no pilot ever suffered from having too much information available, but he has often suffered as a result of having too little information. In those cases where it has been considered that a pilot had too much information, it can usually be shown that the real problem was bad display design in which some information occluded other information and thus reduced the amount available. Every pilot wants as much information about his control situation as is possible as long as it can be used on his own terms. That means having the information when he wants it and not having it intrude when he does not. That is the real challenge for display design.

4.2.3 Symbology and Colors for the Candidate

As stated previously, the use of electronic displays driven by digitally processed information, has made possible a quantum jump in the ratio of display-provided information to pilot-derived information. In fact the set of possible information that can be provided to the pilot has become so large that the limit is now determined by display interpretability rather than signal processing and space for the instruments.

Common Reference Lines

The most general aspect of the design of the displays for interpretability has been that of tying together visually those parameters which, in an information sense, belong together. Consider first the reference lines for reading attitude, track, airspeed, altitude and flight path angle. Whenever these parameters are shown by separate instruments it takes a separate

indication to establish the frame of reference for reading each parameter. In both the 2-D and 3-D displays, as shown in Figure 50, only two lines are required to provide a common "reading" reference for all of these displayed variables. To provide maximum area for the "map" situation symbol on the 2D display, the pitch/path angle and the airspeed altitude references are offset downward shown as bulges which grow out of these reference lines. This latter technique eliminates the requirement for additional discrete elements in the display. By extending these lines toward the edges of the display this reference tends to become a part of the "background" in the sense of Gestalt psychology, and thus does not compete visually in the perception of "figure" in the display. They tend to behave much like dividers in the windshield through which the pilot is looking to see the world beyond.

Attitude Display

Consider the attitude scale provided to show pitch angle and bank angle relative to the common reference. For the following symbology descriptions refer to Figures 51 and 52. Only two or three of these lines will appear at any one time - enough to enclose the reference symbols for fuselage centerline extension and flight path angle. These pitch lines are simple lines extending across the display space so that one line will appear as only one visual object. By that fact they reduce the amount of information in each line to a minimum from the standpoint of the pilot's visual information processing and consequent clutter.

The coding of the pitch lines has been chosen to simplify the amount of information which must be shown and to speed up interpretability. Solid lines are used each ten degrees for negative pitch angles and dashed lines each ten degrees for positive angles. Short indica marks are inserted at two degree intervals. A heading scale, traveling along the horizon line as part of attitude (as well as being a part of situation), is provided for the smooth interpretation of control at large pitch attitude angles. Experiments have shown that when attitude indicators become more pictorial in nature pilots begin to expect movement along the horizon with heading change.

A unique operational feature of the horizontal reference line is provided relative to the attitude-scale aircraft angle of attack increases from 0° the reference line separates to form a

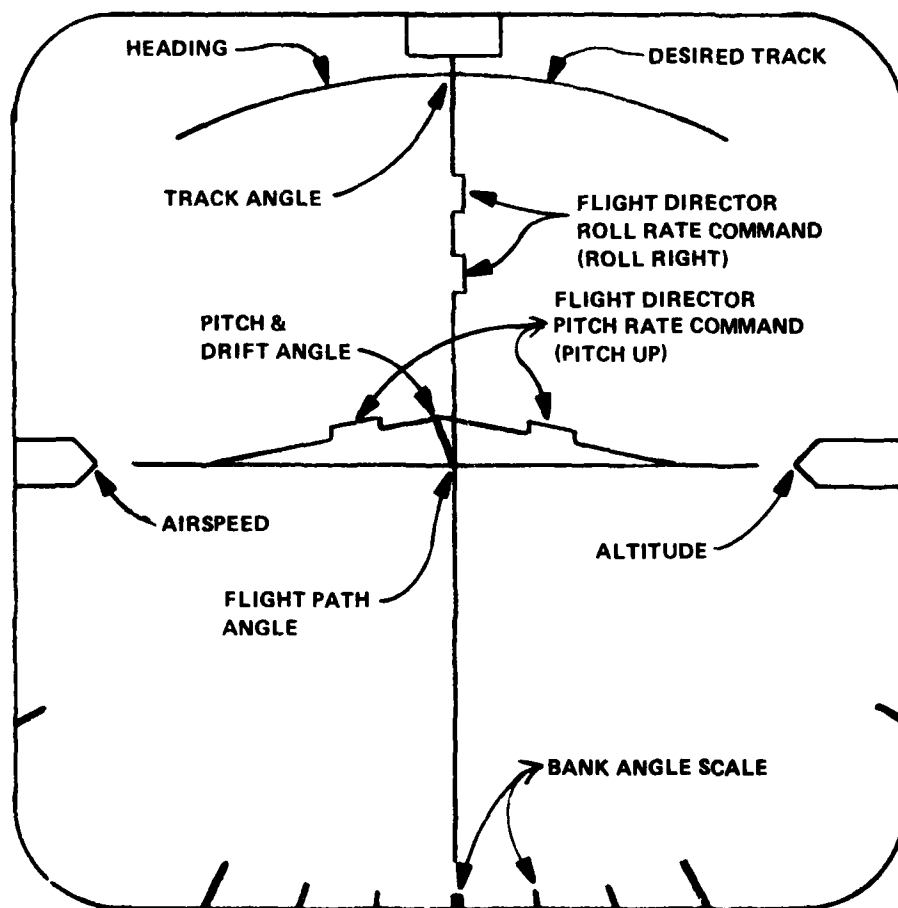


Figure 50 Common Reference Lines For Candidate Displays

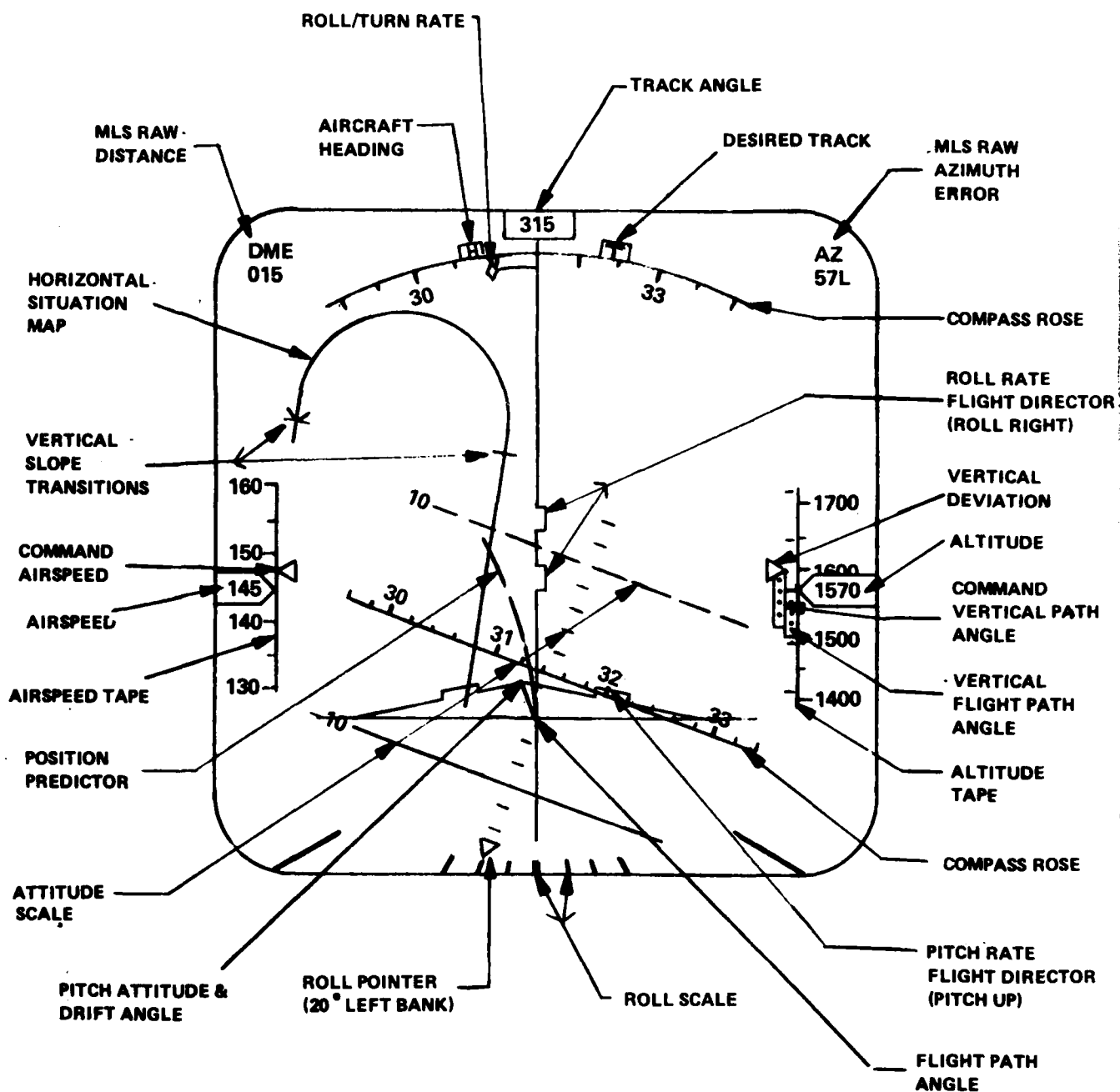


Figure 51 2D Display Symbology

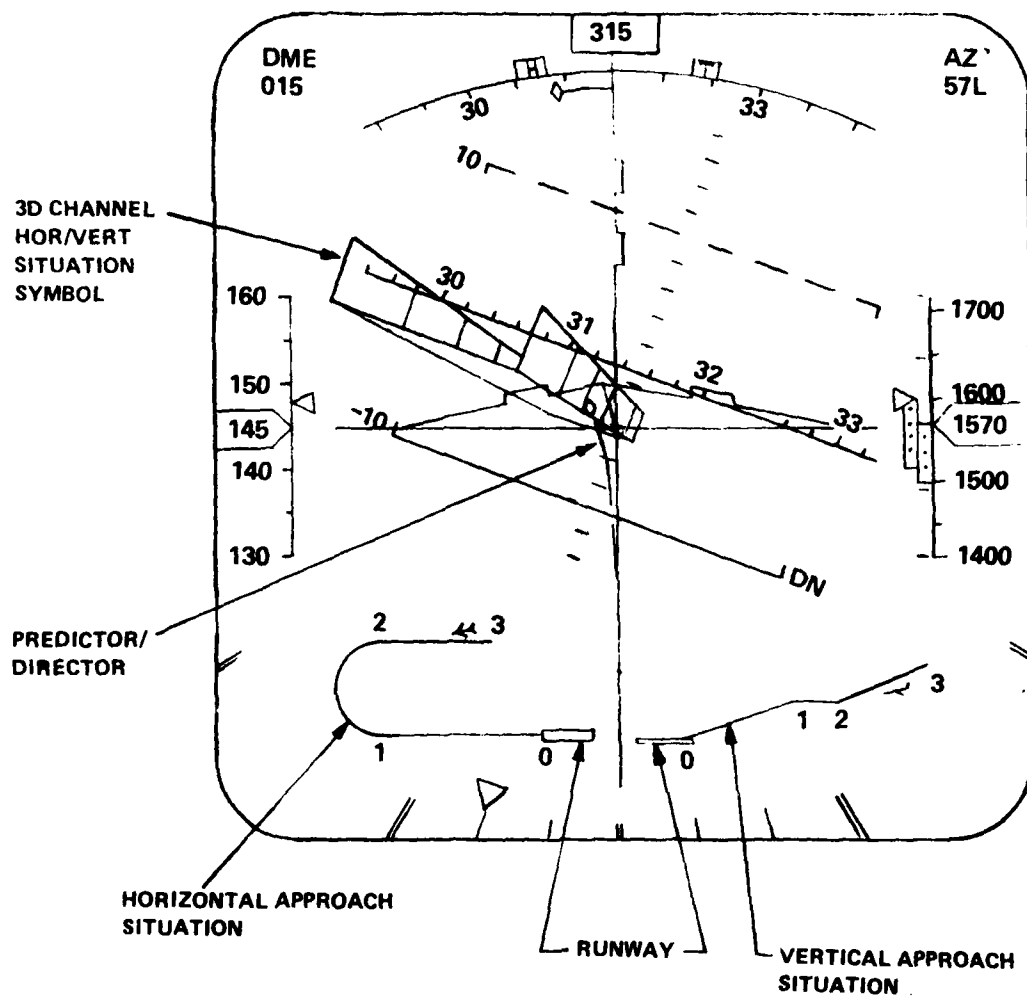


Figure 52 3D Display Symboly

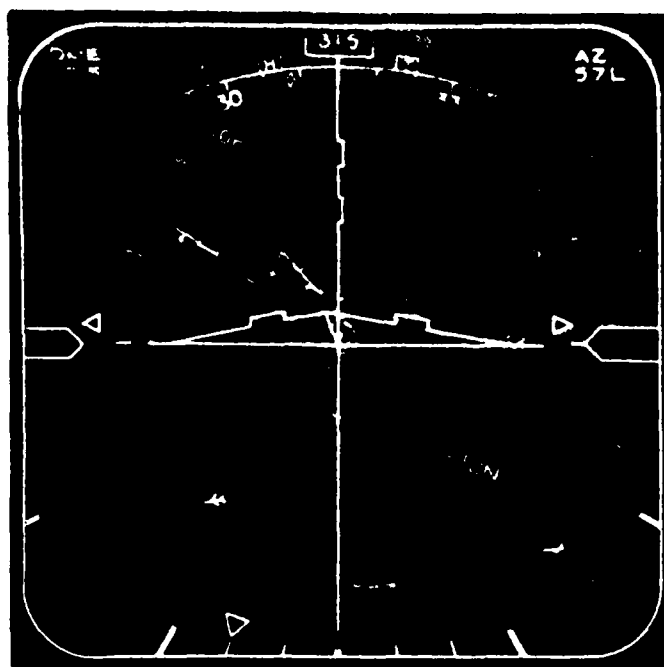


Figure 54 3D Color Display

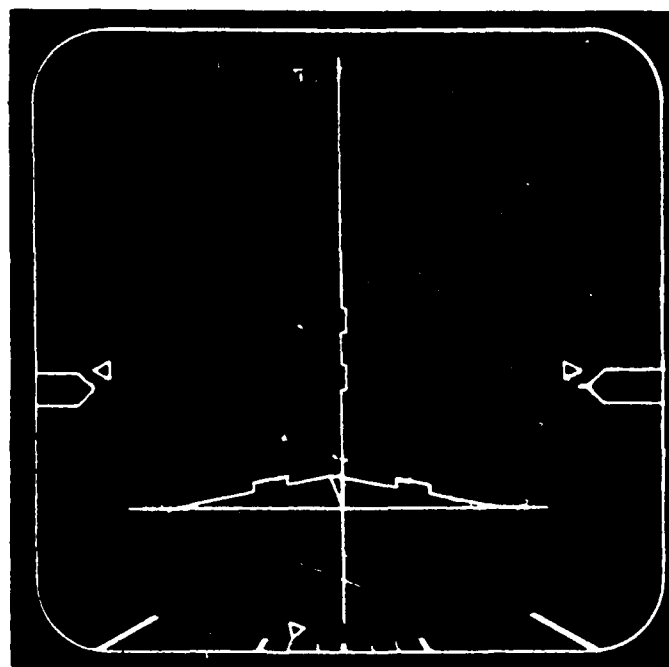


Figure 53 2D Color Display

triangle resembling a delta wing aircraft as viewed from the rear. The horizontal base of the triangle, read against the attitude scale, indicates vertical flight path. The apex of the triangle indicates pitch attitude. Thus, the height of the triangle is proportional to angle of attack. The apex is also displaced laterally as a function of drift angle and thus provides a qualitative indication of that parameter. Roll attitude is indicated by observing this symbol relative to the attitude scale. Actual roll angle is also read via the roll pointer against the fixed roll scale.

Airspeed/Altitude

A moving tape-type scale is used for both airspeed and altitude on the left and right side of the display, respectively. A pointer-shaped box serves as both an index against which the scale may be read and an enclosure for a corresponding digital readout.

Command airspeed is indicated by a second pointer moving with that scale adjacent to the selected value. Thus, airspeed error is indicated by a displacement between the two pointers. The command pointer is limited at the upper and lower extreme of the scale whenever the error exceeds the visible portion.

2D Horizontal Situation

In the case of the 2D display, mapping of the horizontal situation is passed on a track-up display with range and azimuth defined up from the center of the reading reference. At its upper end, the reference constitutes a lubber line for reading ground track against the moving compass rose. A digital readout of track is also provided. Aircraft heading and desired track are indicated on the compass rose with specific pointers. In a display sense, the airplane is always moving up this line in its momentary direction. During turns, the situation rotates under this line. With range and azimuth defined in display space, the horizontal components of the path of the desired vector can now be shown directly in the same coordinates. That portion of the horizontal view of the MLS approach path, within the scaling of the display, is presented in a map situation format with symbols provided along the path to cue the pilot to vertical slope transitions as the approach proceeds toward touchdown. The actual scaling of the display may be variable in the MLS terminal area depending upon the type and phase of approach. A lateral position predictor is provided in this

same display space to indicate further aircraft positions as a function of bank angle, drift angle and airspeed. Each sector corresponds to the next 5 seconds of flight, thus expanding the pilot's comprehension of the horizontal situation and providing an alternate means by which the pilot can couple asymptotically to the desired path.

Digital readouts of raw MLS distance and azimuth error data are provided in the upper corners of the display. This data can be used to continuously cross check the map situation during the various segments of a complex approach. It will also correspond in distance to touchdown and cross track angular error during final.

3D Horizontal/Vertical Situation

The 3-D display uses the same display mapping for attitude as the 2-D. For position information, the 3-D uses up-down and right-left as angles and depends upon the use of perspective to create the illusion of depth as the third dimension for mapping distance. The perspective treatment is limited to the depiction of a channel into which the aircraft is flying. The amount of distance which can be shown in this manner is limited and at present is expected to correspond to the distance that will be covered in 20 seconds at current velocity.

During the final phase of the approach, a runway image will appear in full perspective at the far end of the channel and will appear to grow and vary in shape as a function of distance to touchdown and lateral and vertical displacement relative to the derived path.

A combined lateral and vertical predictor is provided to indicate the future aircraft position as a function of bank angle, drift angle, airspeed and rate of change of vertical flight path. By centering the circular end of this symbol within the far end of the channel, the aircraft will couple to the derived flight path. Thus, its use is an alternate to the flight director bulges in the reference lines.

A plan and elevation view of the specific MLS approach is displayed with the current aircraft positions shown, thus providing the pilot with an overall evaluation of his status during the entire approach.

4.2.4 Vertical Flight Path Angle/Deviation

The most interpretable place for showing relative and quantitative flight path angle is at the altitude lubber line. Closest to the altitude scale is a segmented tape-like symbol which emanates from the lubber line position either up or down. Each segment represents one degree of flight path angle.

To the left of the segmented flight path angle display is a triangular pointer which indicates vertical deviation from the desired path. Growing out of the center of that triangle is a segmented tape which shows the slope of the commanded path. Again each segment represents one degree. With the efficiency of shared references, the pilot can readily see the comparison of actual and desired vertical position and the comparison of actual and desired vertical flight path angles. All these parameters are read at the point at which he reads his altitude. In this form they can all be read clearly while providing a minimum of interference with the rest of the display.

Roll/Turn Rate

Emanating from the vertical reference line close to the compass scale is a thin tape which displays turn rate. At the active end of the turn rate tape is a green diamond which displays roll rate. When roll rate is at zero, the green roll rate diamond is at the active end of the green turn rate tape.

The compass rose at the top of the display is a major element in pilot situation control. With regard to this scale, he is flying (tracking) straight up the display. In the 2-D display features to the right or left of his path are shown in the same relative position as in the outside world. Thus there are some very important reasons for having these major display elements in just this orientation.

Designing the moving compass scale to achieve these major relationships induces a cost in pilot reading errors. A moving scale such as this must violate one or more principles of human engineering design. One such principle is that a progression of numbers should increase from left to right. Another is that when things move they should be arranged so that movement to the right or clockwise means an increase.

It is readily apparent that a moving scale must violate one or the other of these principles if it is read at the top. And this one does. The consequences as stated in human engineering design terms is that violation of the principles leads to operator error. In a series of studies in 1956 and 1957, published in 1957 and 1958, Ritchie and Bamford established that the moving card compass does indeed lead to pilot control reversals. They also published an experimentally determined way to alleviate the problem.

That method of reducing the number of control reversals from the use of the moving card compass involved the association of the place at which the compass was read with a display of turn rate and quickened turn rate. By putting them in the relations in which they are shown on the 2-D and 3-D display, they reduce to a marked degree the number and duration of control reversals.

The reasons these two elements reduce control reversals is that they respond much more quickly than heading to aileron movement and their direction is compatible with the direction of aileron control movement. Being in the relation shown to the heading lubber line they act like a vernier and they allow asymptotic roll outs to specific headings by pointer matching.

The presence of these two displayed elements provides additional correlated flight parameters for those occasions when the pilot does systematic cross checking to verify that some of his data inputs are accurate.

Further rationale and details of the various symbology are contained in Appendix

Summarizing The Systematic Use Of Color On The Displays

One color is used in the display to represent the aircraft reference, i.e., those things which remain fixed or nearly fixed relative to the bezel. The crossed reference lines are made as long and as continuous as possible to function similar to window pane dividers - you look past them to see objects. This accounts for most of the use of yellow in the display.

Of the two remaining colors, green has been assigned to attitude and those parameters that belong in the time frame of attitude.

Red has been assigned to those functions dealing with position.

In some cases, there has been a departure from strict adherence to these rules in order to minimize confusion. The scale on the bottom of the display quantifies bank angle and strictly speaking should be green. In the case of the 2-D display, the proximity to the pitch reference lines is such that use of another color makes the display less confusing. Yellow was chosen since the scale is fixed on the bezel and is related to the aircraft reference. Yellow was chosen for a similar reasons for airspeed command and the vertical deviation scale.

There are two scales and two colors used for compass information. The one along the horizon is green because heading belongs as a part of attitude control, especially at large pitch angles where it is necessary to include the third dimension in attitude reference to allow smooth control based on straight forward interpretability. The red compass scale at the top of the display is that color because it is involved in position control as opposed to attitude control. That may best be emphasized by noting that the primary mode in which this display is read is the direction of the ground track. The marker for heading is in a secondary position on this scale.

The channel needs to be visually separable from the yellow aircraft reference lines and from the green attitude display. Since it is involved with aircraft position, the choice of red is consistent and also provides the necessary color separation.

4.2.5 The 2-D/3-D Display Concepts

In the color 2-D display shown in Figure 53, the vast amount of information displayed to the pilot has been achieved by having a dual mapping of the same display space in conjunction with the availability of color right-left and up-down in display space is defined as azimuth and elevation for the green set of attitude data and as azimuth and range for the red set of track data.

The systematic use of color and other design techniques has been employed to minimize interference between these two mappings of the same display. It is expected that simulator evaluations will verify the merits of this approach.

An alternate concept, the color 3-D display, utilizes a second major design approach to preserve the consistent mapping of the display space into azimuth and elevation and to map distance by creating the illusion of depth in the display. The most powerful single tool for generating the illusion of depth is linear perspective.

This approach to display design has been implemented as shown in Figure 54. In the same display space, the fixed reference is shown in yellow, the attitude display in green, and the perspective picture of the commanded flight path (with predictor) in red.

The form of the major perspective feature is the channel concept, which was examined experimentally by Kraiss and Schubert in Germany, and by others in this country. Perceptually, it presumes that the pilot will position his aircraft in height even with the top of the channel sides and laterally over the center line of the channel. The predictor originates as if from a point on the fuselage slightly below eye level. The channel extends to a point in space corresponding to approximately 20 seconds of flight time. The path predictor will extend through the same time figure.

Two total view situation displays are provided to enable the pilot to assess his overall position relative to the complete approach profile.

4.2.6 The Relative Advantages And Disadvantages Of The 2-D And 3-D Displays

In comparing the 2-D and the 3-D displays, one must look first to what is maximized in each and what is compromised most in each.

In the case of the 2-D display, the pictorial view of the horizontal situation is maximized. With most of the display space available for the purpose, it allows him to visualize directly the situation in its geographical coordinates relative to his own velocity vector. He sees in some detail the situation in which he will operate in the next several minutes. He has the information required to put himself and other features into conceptual relation with his path over that time.

The 3-D display maximizes the visualization of the situation to be encountered in the next 20 seconds. As such, it is something of an extension of the attitude control loop. With that extension, the pilot should find his attitude control task easier and more effectively performed.

The comparison of 2-D and 3-D is that the former gives the best aid to situation interpretation and path planning while the latter gives the best aid to attitude control and short-time path control.

The major theoretical problem for the 2-D display is that it combines azimuth-elevation and azimuth-range coding in the same display space. It does that to maximize the sensitivity of situation display.

The major theoretical problem for the 3-D display is that its effect depends on creating the illusion of depth within the azimuth elevation coordinates. There is a limit to the useful perception of this depth, and a limit to how accurately the pilot can derive the information he needs for control. An attendant cost is the considerable amount of computation which must be done to present the channel in perspective in real time at the required up-dating rate.

The 3-D display evolves naturally out of control engineering while the 2-D comes more naturally from task analysis and operational pilot comments

4.2.7 The Choice of "Inside-Out" Displays

The "inside-out" configuration for attitude is recommended for both the 2-D and 3-D displays for the following reasons:

- **Complex Display Simplification**

Each of the proposed displays incorporates two crossed lines serving as a common reference for several primary displayed variables. This characteristic has greatly simplified the display when compared to other methods of displaying an equal number of parameters.

The common reference lines cannot be used with an "outside-in" format. In "outside-in" the coordinates of the cockpit and instrument panel represent earth-reference coordinates

for display-mapping purposes. Each displayed parameter must have its scale fixed somewhere in this space and have a moving element in that space denote the indexed value of the parameter. It seems necessary then for each scale to have a relatively independent coordinate system, thus increasing the number of display indices when compared with the complex displays as shown.

The opportunities for simplification through common references is illustrated in Figure 50. Note that the pitch rate and roll rate commands of the flight director are a part of the two reference lines for reading attitude. No separate indications are required, thus reducing clutter or visual noise.

In a similar manner the horizontal reference line splits into two parts to show both pitch attitude and flight path angle. The center of the pitch reference also moves laterally with drift angle.

The resultant image pictorially resembles a delta wing aircraft whose "nose to tail" projected height corresponds to angle of attack and whose lateral nose displacements is a function of drift angle.

- Other ways to obtain control-and-display compatibilities

There are indeed a number of experiments in which some advantages have been shown for a moving airplane or "outside-in" concept. However, there are two main disadvantages to this concept. One is that the displays have tended to be quite ambiguous from the standpoint of interpretability. The other characteristic is that they depended upon motion in the display to confirm that the control was moved in the right direction.

In the proposed displays, it will be seen that great care has been taken to keep the display from being ambiguous. There can be very little doubt on the part of an experienced pilot about the major elements of motion relations.

One element of these displays, the moving scale compass, has been shown experimentally to be misinterpreted occasionally resulting in control reversals. On both the 2-D and the

3-D display a turn and roll rate symbol is displayed at the reading reference for the compass. Both roll rate and turn rate respond more quickly to aileron control movement than does the heading scale. The two rate symbols, therefore, set the direction for aileron control movement and are compatible with the control in motion relations.

- Compatibility with the Head-Up Displays

Head-up displays are already common in high performance aircraft. As their technology matures and costs decrease, much more wide-spread usage can be expected.

It is inherent that head-up displays are used while the pilot is looking at the outside world and simultaneously observing images reflected off the combining glass. It is necessary that they be inside-out to fit into this framework of use. A predictable penalty will result in performance if pilots who have an inside-out reading habit developed by the use of a head-up display are provided an outside-in head down attitude display.

- Existing "Inside-Out" Perceptual Habits

Most aircraft flying in this country today have "inside-out" attitude displays. Thus, at present most trained pilots have developed a reading habit to fit the inside-out format. Displays involving competing reading habits should not be mixed without a cautious consideration of the penalties.

- Compatibility with All-Attitude Indicator

All-attitude indicators in service today employ the "inside-out" concept. Even if desired, it appears to be quite impossible to build an "outside-in" attitude indicator which will operate through all attitudes with smooth linear motion. The reason is that the pilot has a fixed viewing position in cockpit space and thus loses one degree of freedom in that space. The mapping of attitude onto display space for outside-in assumes that the coordinates of the cockpit represent earth-reference space. Since he has lost a degree of freedom in that space he will sometimes see his representation as flying toward himself, sometimes away, etc.

4.2.8 Extension of the 3-D Channel Near End to the Display Extremes

The 3-D display is a complex display designed to provide a great deal of information to the pilot which is critically useful to him. The several elements of the display must be carefully designed to provide the information required by the pilot and to do that without unnecessarily increasing his perceptual workload.

One of the ways to calculate the amount of information in a display is to count the number of discrete elements shown. The effect of visual noise on the part of the pilot follows somewhat the calculation of "bytes" first used by Shannon and Weaver.

The simple calculation of bytes of information presumes that the elements are uncorrelated. In matters dealing with displays upon which humans can impose meaning, the calculation of information transmitted can be influenced to a phenomenal degree. The Gestalt psychologists showed some fifty years ago that human perceivers can organize a scene into perceptual units by grouping and handle a large number of now-related elements as if they were one unit. Another way to say this is that pictorial quality in a display can serve to make a massive change in the apparent information-handling ability of the perceiver.

In the 3-D display there are three different sets of elements sharing the same display space: (1) the reference lines representing the viewing frame, (2) the pitch lines which allow attitude angles to be read, and (3) the channel. The channel has been carefully designed to provide the illusion of distance looking into the display. By providing the illusion of distance the channel allows the depiction of future desired path changes.

The illusion of distance suffers somewhat if the channel ends somewhere in front of the pilot and there is no good clue for him to be able to judge how far away it is. By being some distance away it also tends to be seen as an object, and as such not necessarily a three-dimensional reference.

If the lines of the channel extend to the limits of the

display space, there is less doubt on the part of the pilot about what his relation to it is. Like the difference between being on the runway and approaching it, there is a good bit of difference in the accuracy and assurance of perceived relations.

It is probably true that extending the channel at the near end will reduce the apparent perceptual workload in interpreting it. The pilot will tend to see it as a whole as one of the references for flight. If it is only out in front of him he will likely take more time to interpret it in relation to himself, and there will be more of a tendency to examine its parts separately to evaluate its orientation relative to himself. That adds up to more perceptual workload.

There may be some details (e.g. apparent thickness of stroke lines) which will change the predicted perceptual response. Simulation of the display in the extended form should provide a test of this hypotheses and allow a comparison with the truncated version.

4.3 Electronic CDU Candidate Configurations

Three MLS CDU candidates are described in the following paragraphs which integrate all of the control functions required for MLS complex trajectory flight. These units have been designed for mounting on either the center pedestal or side console. Each candidate is adaptable to accept and display data from an automatic entry source. For manual operation, each candidate requires approximately 50 key strokes to enter all the frequency and geometry data required to fully define a complex trajectory consisting of three lateral and two vertical path segments. Less key operations are required for trajectories with fewer segments. Less key operations are required for trajectories with standard turn radii.

These units combine the functions of the Phase III MLS control panel and auxiliary data panel. By integrating the channel select function in the CDU an availability problem could result. This will depend upon a reliability comparison of the CDU and a simple channel selector. No such analysis has been made for this study.

The two major human factor problems associated with the T-39 CDU have been corrected with these designs. These are as follows:

- A keyboard has been substituted for the non-detented incremental encoder knob to provide faster and more positive data insertion.
- Logic has been provided to visually prompt the pilot and lead him to his next piece of data to be entered.

This has essentially eliminated the need to memorize procedures and has eliminated the resultant loss of place due to distractions. This, in turn, results in less errors and/or the time-consuming reinitiation of a procedural sequence.

Of the three designs, Candidate Number 3 appears to be the most attractive. It provides for relatively easy operation and utilizes pilot relatable data and push-button terminology. Simulation is required, however, to

determine if any of these designs is truly acceptable from a pilot workload aspect. It is doubtful that any of these (or any other design for that matter) are useable for manual data entry in a single-seat aircraft.

4.3.1 CDU Candidate Number 1

A candidate MLS configuration for data entry, described herein, has been devised to provide maximum capability and versatility with minimum equipment. The functions previously associated with the MLS Control Panel and the MLS Auxiliary Data Panel are all handled by a new CDU shown in Figure 55.

A wide variety of approaches can be accommodated including U's, intercepts, Z's, multiple segments, direct and straight-ins as shown in Figure 56. Data defining the particular approach path required by the MLS computer can be retrieved from internal storage; or entered manually via the CDU. The system can be adapted to accept approach path data received via the MLS ground to air data link or any other ground-to-air link such as the newly proposed Discrete Address Beacon System (DABS), or entered via an automatic card/tape reader.

To simplify the manual entry of data, a procedure has been established requiring a minimum of pilot activity. Several standard type approaches have been established and are recognized by the computer via a pilot selected identification code. Depending upon the particular approach type, other pilot inputs are made to adjust the intercept angle, final distance, turn radius, and other parameters as necessary. Table 6 summarizes the inputs required for each type approach. A maximum of ten input parameters are required to tune, identify, and define the most complex multiple segment trajectory handled by the system. The most simple straight-in approach requires only two. These parameters are defined as follows:

- | | |
|------|--|
| CHAN | - Channel code associated with frequency selection for a particular MLS installation |
| APPR | - Approach type identifier (see Figure 2 & 3). Numerics in code indicate vertical path |

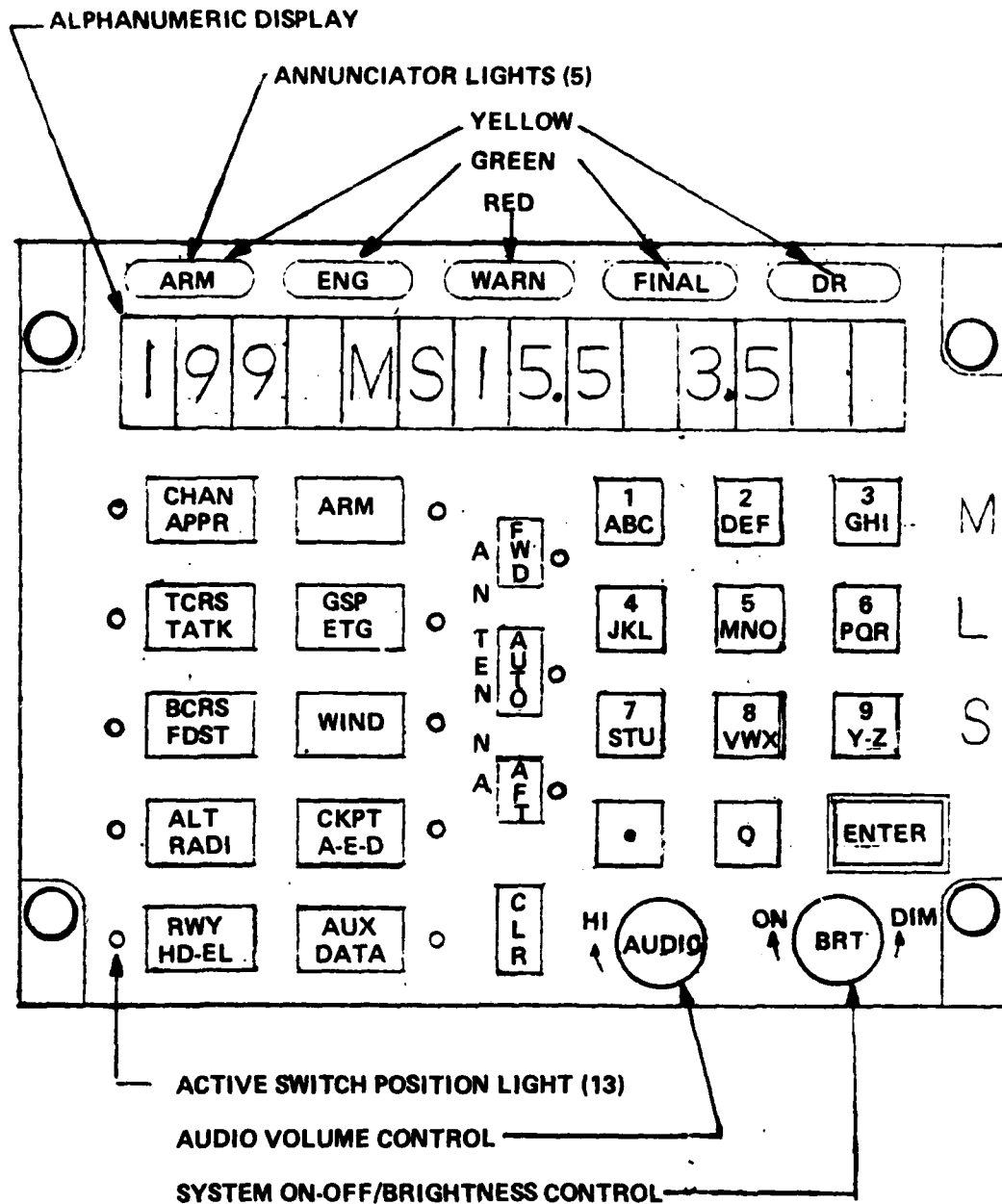


Figure 55 MLS CDU Candidate Number 1

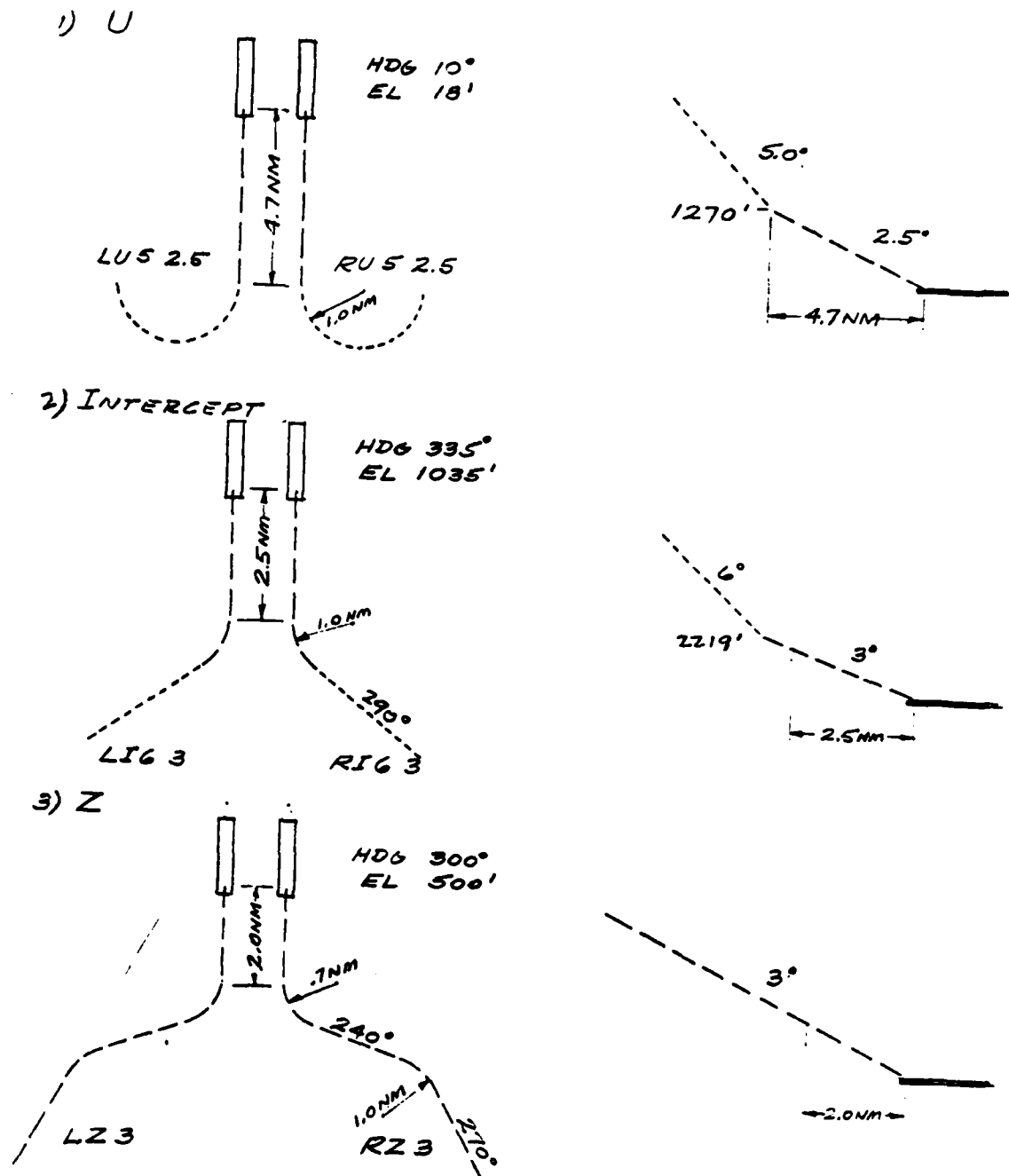
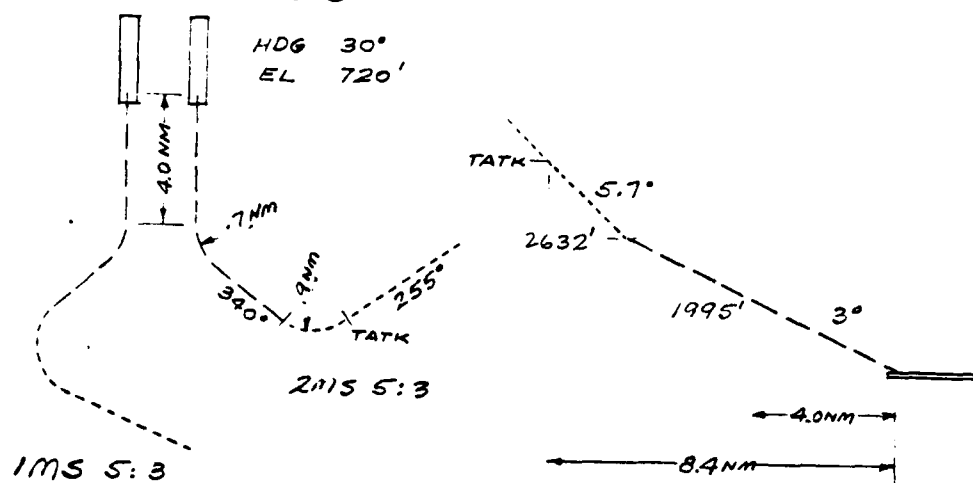
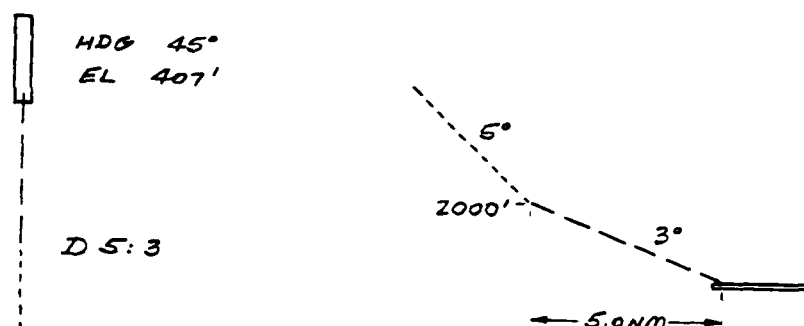


Figure 58 Typical Approach Types

4) MULTIPLE SEGMENTS



5) DIRECT



6) STRAIGHT IN

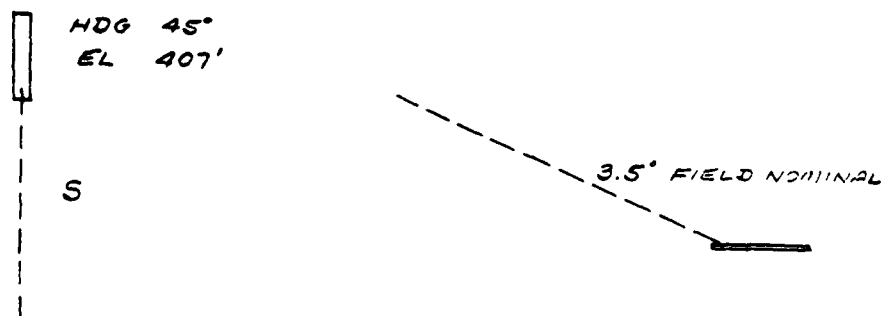


FIGURE 3 - APPROACH TYPES

Figure 56 Typical Approach Types - Continued

TABLE 6
Input Parameters to Define Approach

APPROACH TYPE	SWITCH POSITION	CDU D I S P L A Y			
		INITIAL		SET	
1)	CHAN/APPR	SET	SET	199	RU 5 2.5
	TCRS/TATK	NR	NR	NR	NR
	BCRS/FDST	NR	SET	NR	4.7
	ALT/RADI	SET	SET	1270	1.0
	RWY HD/EL	SET	SET	10	18
2)	CHAN/APPR	SET	SET	163	RI 6 3
	TCRS/TATK	NR	NR	NR	NR
	BCRS/FDST	SET	SET	290	2.5
	ALT/RADI	SET	SET	2219	1.0
	RWY HD/EL	SET	SET	335	1035
3)	CHAN/APPR	SET	SET	131	RZ 3
	TCRS/TATK	SET	NR	270	NR
	BCRS/FDST	SET	SET	240	2.0
	ALT/RADI	NR	SET	NR	1.0 0.7
	RWY HD/EL	SET	SET	300	500
4)	CHAN/APPR	SET	SET	129	2MS5.7 3
	TCRS/TATK	SET	SET	255	8.4
	BCRS/FDST	SET	SET	340	4.0
	ALT/RADI	SET	SET	2632	0.9 0.7
	RWY HD/EL	SET	SET	30	720
5)	CHAN/APPR	SET	SET	115	D5 3
	TCRS/TATK	NR	NR	NR	NR
	BCRS/FDST	NR	NR	NR	NR
	ALT/RADI	SET	NR	2000	NR
	RWY HD/EL	SET	SET	45	407
6)	CHAN/APPR	SET	SET	085	SI 3.5
	TCRS/TATK	NR	NR	NR	NR
	BCRS/FDST	NR	NR	NR	NR
	ALT/RADI	NR	NR	NR	NR
	RWY HD/EL	SET	SET	45	407

* NR -- Not Required

angles (two maximum)

TCRS	- Course of first MLS segment following enroute navigation for three (3) segment approach.
TATK	- Distance from start of the first transition within MLS coverage to GPIIP
BCRS	- Course of base leg to final
FDST	- On course distance of final approach segment
ALT	- Transition altitude from first vertical descent path to final descent path
RADI	- Radius of turns (two selectable maximum)
RWY HD	- Heading of MLS runway
RWY EL	- Runway elevation at GPIIP

● SYSTEM DESIGN PARAMETERS

- A maximum of two vertical paths and three horizontal segments may be selected with the system
- Resolution established for selectable parameters is as follows:

Heading/Track Angles	1 ⁰
Vertical Path Angles	0.1 ⁰
Along Track & Final Distance	0.1 NM
Turn Radii	0.1 NM
Transition Altitude	1 FT
Runway Altitude	1 FT

- All control & display functions required for MLS operation can be accomplished via one CDU including channel select, auxiliary data monitoring, antenna control, etc.
- All test and maintenance information is provided via the CDU switches and display

● CDU DESCRIPTION

The CDU in conjunction with eight instruments, is the pilot's total interface with the MLS system. Its operation is described in the following paragraphs. Following the description, step by step operational examples are given for minimum and maximum complexity approaches.

- Data Input/Verification Switches, Controls and Indications

Within the group of 10 pushbuttons on the left side of the CDU, nine are provided to accommodate the data input/verification function. All are electronically interlocked such that only one may be active at a time. With the exception of the AUXILIARY DATA switch, any one of the nine in the active state may be deactivated by repushing that switch or any of the remaining eight. When all nine switches are deactivated, the alphanumeric display reverts to its normal operating mode.

- AUX DATA Switch

The AUX DATA switch, when pushed will deactivate any of the remaining eight. However, multiple pushes of this switch are necessary to cycle through the various data which then appears sequentially on the alphanumeric display.

This switch is also used in conjunction with the ENTER pushbutton to accept data from an external source such as a card or magnetic tape reader.

- ARM Switch

Activating the ARM switch places the system in a state of readiness to engage once the received MLS signal strength is adequate for operation. Several conditions have to be

met before it's possible to ARM such as 1) all input data must be in memory for the particular approach contemplated 2) the computer must have satisfactorily solved the navigation equations 3) all data link information must have been received.

- Alphanumeric Keyboard

The Alphanumeric Keyboard and decimal key are used to manually enter all required MLS approach data as described elsewhere. As presently envisioned, the full alpha keyboard is not required, only approximately the nine being used. The computer can recognize the single push of a specific key and determine whether a numeric or alpha is required at a particular location in the input sequence. At this point in the program, however, it is recommended that the potential for full alphanumeric capability be available to accommodate changes that may occur during the simulation and/or flight test phases. As an example, in conjunction with the AUX DATA switch, specific navigation, flight, test, etc. data could be called up to be displayed by keying in the necessary alphanumeric code.

- CLR Switch

The Clear switch is used to correct data entry errors and/or modify stored data by clearing the unwanted character(s) allowing new data to be entered. A single rapid push of this switch (held less than 1 second) will clear one character to the left of the cursor as seen on the alphanumeric display. Holding the switch in longer than 1 second will clear all data to the left of the cursor.

- ENTER Switch

The ENTER switch is used to enter the data, set up on the alphanumeric display, into memory. It is also used in conjunction with the AUX DATA switch to enter data from an external source if the system is so equipped.

By keying in a specific approach identity code and pushing ENTER, the computer will search memory to extract the required data. If the data is contained in memory, this will eliminate the necessity of manual entry.

- Annunciators

Five annunciator lights are provided to indicate ARM, ENGage, WARNing, FINAL approach, and Dead Reckoning status. Additional annunciators may be provided along the left and right edges of the panel if simulator and/or flight tests prove their necessity or desirability.

- Antenna Control

Three pushbuttons are provided to control the antenna mode. Normally, when the system is turned ON, the antenna automatically enters the AUTO mode. In the event of an actual or suspected failure of the AUTO mode, the receiver may be switched to the Forward or AFT antenna using the appropriate pushbutton. Electronic interlocking will allow only one of the three switch positions to be active at one time.

- Audio Control

The AUDIO Control, consisting of two concentric knobs, is used to adjust the volume of the MLS angle and DME receiver audio identifying codes.

- On-Off/BRT Control

The Brightness Control with its integral ON-OFF Switch allows the pilot to activate the system and control brightness of all lighted elements on the CDU.

- Alphanumeric Display

A choice of alphanumeric display will be based upon the following preliminary requirements:

• Characters	Alphanumeric
Number	14 nominal
Height	0.3" approx.
• Display size	4 5/8" W x 5/8" H
• Type	LC, Incandescent, or LED
• Color	White
• Brightness	Sunlight readable

- Operational Features

All switches and keys are momentary type with positive feel. Hold and interlocking functions as described later, are accomplished electronically.

"Jewel" lights are provided adjacent to each control switch to indicate when a particular switch has been activated.

- Approach Parameter Selection Ranges:

Initial Vertical Descent Path Angle	0-19.9°
Final Vertical Descent Path Angle	1- 9.9°
Course/Heading	0-359°
Final Approach Distances	1.5-15 NM
Transition Along Track Distance	1.5-30 NM

PILOT ACTIVATED SW.	DISPLAY	COMMENTS
ON	ALL LIGHTS & TEST CHARACTERS ON FOR 2-3 SECONDS & THEN CHAN/APPR SW. ON C H A N A P P R	ANTENNA TO AUTO CHAN/APPR LIGHT ON
0	0 - A P P R	CURSOR(-) BLINKS AT NEXT INPUT LOCATION
8	0 8 - A P P R	
2	0 8 2 A P P R	
S	0 8 2 S -	
ENTER	BLANK FOR 1/2 SECOND 0 8 2 S 3.5	COMPUTER SEARCHES FOR NOMINAL VERT. PATH FOR STRAIGHT IN APPROACH RCVD. VIA DATA LINK
RWY HD•EL	H D G E L E V	CHAN/APPR LIGHT OUT
0	0 - E L E V	
4	0 4 - E L E V	
5	0 4 5 ° E L E V	
4	0 4 5 ° 4 -	
0	0 4 5 ° 4 0 -	
7	0 4 5 ° 4 0 7 -	
0	0 4 5 ° 4 0 7 '	
ENTER	BLANK FOR 1/2 SECOND 0 4 5 ° 4 0 7 '	READ BACK FROM MEMORY
ARM		ARM ANNUNCIATOR ON
RWY HL•EL	NORMAL OPERATION	RWY HD•EL LIGHT OUT

EXAMPLE OF CDU OPERATION
STRAIGHT IN (MINIMUM COMPLEXITY)

PILOT ACTIVATED SW.	DISPLAY	COMMENTS
ON	ALL LIGHTS AND TEST CHARACTERS ON FOR 2-3 SECONDS & THEN CHAN/APPR SW. ON C H A N A P P R	ANTENNA TO AUTO CHAN/APPR LIGHT ON
1	1 - A P P R	CURSOR (-) BLINKS AT NEXT INPUT LOCATION
2	1 2 - A P P R	
9	1 2 9 A P P R	
ENTER	BLANK FOR ½ SECOND 1 2 9 A P P R	COMPUTER SEARCHES FOR APPROACH DATA. IF IN MEMORY DATA WOULD APPEAR IN PROPER LOCATION & NO FURTHER PILOT ENTRY RQD.
2	1 2 9 2 -	
M	1 2 9 2 M -	
S	1 2 9 2 M S -	
5	1 2 9 2 M S 5 -	
.	1 2 9 2 M S 5.-	
7	1 2 9 2 M S 5.7 -	
3	1 2 9 2 M S 5.7 3.-	
ENTER	BLANK FOR ½ SECOND 1 2 9 2 M S 5.7 3.0	COMPUTER RECOGNIZES NEED FOR DECIMAL. COMPUTER WILL ASSUME ZERO FOLLOWING DECIMAL READ BACK FROM MEMORY
✱TCRS/TATK	T C R S T A T K	CHAN/APPR LIGHT OUT
2	2 - T A T K	
5	2 5 - T A T K	
5	2 5 5 ° T A T K	

EXAMPLE OF CDU OPERATION
MULTIPLE SEGMENTS (MAXIMUM COMPLEXITY)

PILOT ACTIVATED SW.	DISPLAY		COMMENTS
8	2 5 5°	8 -	
.	2 5 5°	8.-	
4	2 5 5°	8.4 NM	
ENTER	BLANK FOR ½ SECOND		READ BACK FROM MEMORY
	2 5 5°	8.4 NM	
*BCRS/FDST	B C R S	F D S T	T CRS/FDST LIGHT OUT
4	4 -	F D S T	
4	4 4 -	F D S T	
0	4 4 0°	F D S T	COMPUTER RECOGNIZES ERROR. 4 ⁴⁰ BLINKS CLR HELD >1 SEC. CLEARS LAST CHARAC- TER ENTERED
CLR	-	F D S T	
3	3 -	F D S T	
4	3 4 -	F D S T	
1	3 4 1°	F D S T	
CLR	3 4 -°	F D S T	
0	3 4 0°	F D S T	
4	3 4 0°	4 -	
.	3 4 0°	4.-	
0	3 4 0°	4.0 NM	
ENTER	BLANK FOR ½ SECOND		READ BACK FROM MEMORY
	3 4 0°	4.0 NM	
*ALT/RADI	A L T	R A D I	B CRS/FDST LIGHT OUT
2	2 -	R A D I	
6	2 6 -	R A D I	
3	2 6 3 -	R A D I	
2	2 6 3 2-	R A D I	

EXAMPLE OF CDU OPERATION
MULTIPLE SEGMENTS (MAXIMUM COMPLEXITY) (CONTINUED)

PILOT ACTIVATED SW.	DISPLAY		COMMENTS
.	2 6 3 2 . ' R A D I		COMPUTER RECOGNIZES •AS END OF ALT INPUT
.	2 6 3 2 ' 0.-		
9	2 6 3 2 ' 0.9,-		
.	2 6 3 2 ' 0.9,0.-		
7	2 6 3 2 ' 0.9,0.7 NM		
ENTER	BLANK FOR $\frac{1}{2}$ SECOND		
	2 6 3 2 ' 0.9,0.7 NM		READ BACK FROM MEMORY
*RWY HD•EL	H D G	E L E V	ALT/RADI LIGHT OUT
0	0 -	E L E V	
3	0 3 -	E L E V	
0	0 3 0	E L E V	
7	0 3 0	7 -	
2	0 3 0	7 2 -	
0	0 3 0	7 2 0 -	
.	0 3 0	7 2 0 ' 0.9,0.7 NM	
ENTER	BLANK FOR $\frac{1}{2}$ SECOND		
	0 3 0	7 2 0 ' 0.9,0.7 NM	
*CKPT A•E•D	3 5 0°	4.1° 1 7.1 NM	RWY HD•EL LIGHT OUT
*ARM	3 5 0°	4.1° 1 7.1 NM	ARM ANNUNCIATOR ON

EXAMPLE OF CDU OPERATION
MULTIPLE SEGMENTS (MAXIMUM COMPLEXITY) (CONTINUED)

PILOT ACTIVATED SW.	DISPLAY	COMMENTS
AUX DATA	E X T E R N A L L O A D ?	USED WITH AUTOMATIC DATA ENTRY UNIT. IF YES PUSH ENTER
AUX DATA	N W K 1 0 R C A T 2	FACILITY IDENTIFICA- TION CATEGORY
AUX DATA	R W Y 3 2 7° 1 5 0 0 0'	RUNWAY HEADING AND LENGTH
AUX DATA	R V R 3 0 0 0 ' W E T	RUNWAY VISUAL RANGE & STATUS
AUX DATA	C L I 5 0 0 0' B 2 9.9 2	CEILING, BAROMETER SETTING
AUX DATA	R W Y W D 3 2 7° 5 0 G 7 0	RUNWAY WIND DIREC- TION, SPEED & GUSTS
AUX DATA	A Z L I M 3 5 0 L Z 8 0 R	AZIMUTH SECTOR LIMITS
AUX DATA	V P M I N 1.8°	MINIMUM VERTICAL PATH
AUX DATA	T E S T C O D E ?	USED IN CONJUNCTION WITH A/N KYBD FOR TEST & MAINT.
AUX DATA	E X T E R N A L L O A D ?	SEQUENCE REPEATED

EXAMPLE OF CDU OPERATION
AUXILIARY DATA

4.3.2 CDU Candidate Number 2

A "general case candidate for entering MLS approach parameters uses data in a format such as that shown on approach chart RWY13-257, Figure 57. Any conceivable complex trajectory approach can be handled in this manner. With the exception of turns, each segment from transition to transition, horizontally or vertically, is defined in terms of course, along track range, and vertical path angle. For turns, the direction and radius are entered. The information is entered exactly as shown on the chart, and during verification, is displayed exactly as on the chart. As is evident from Figure 58, the same CDU as previously described can be adapted to perform this "general case" operation. An example of pilot/CDU interaction follows.

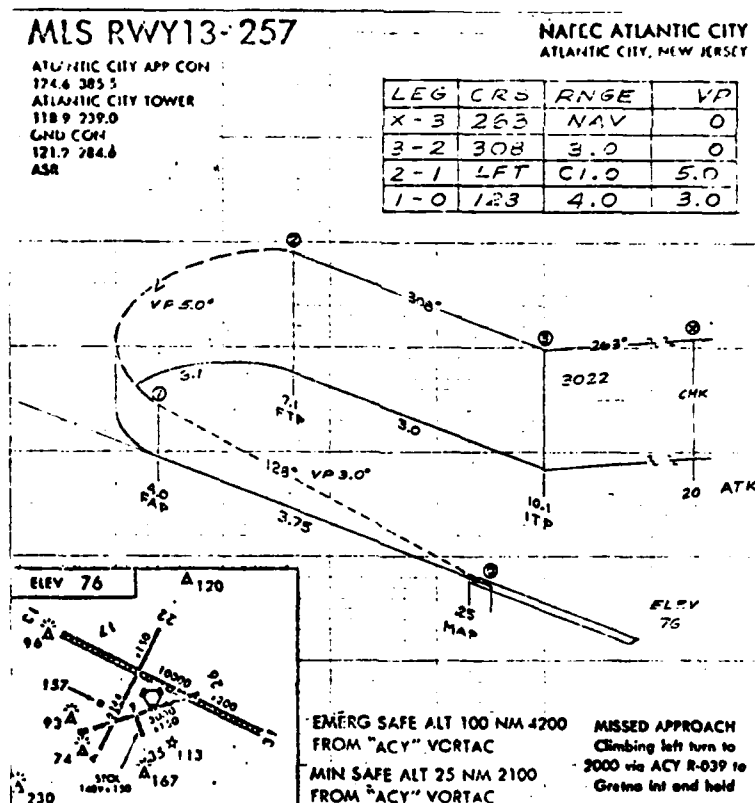


Figure 57 MLS RWY 13-257 Approach Chart

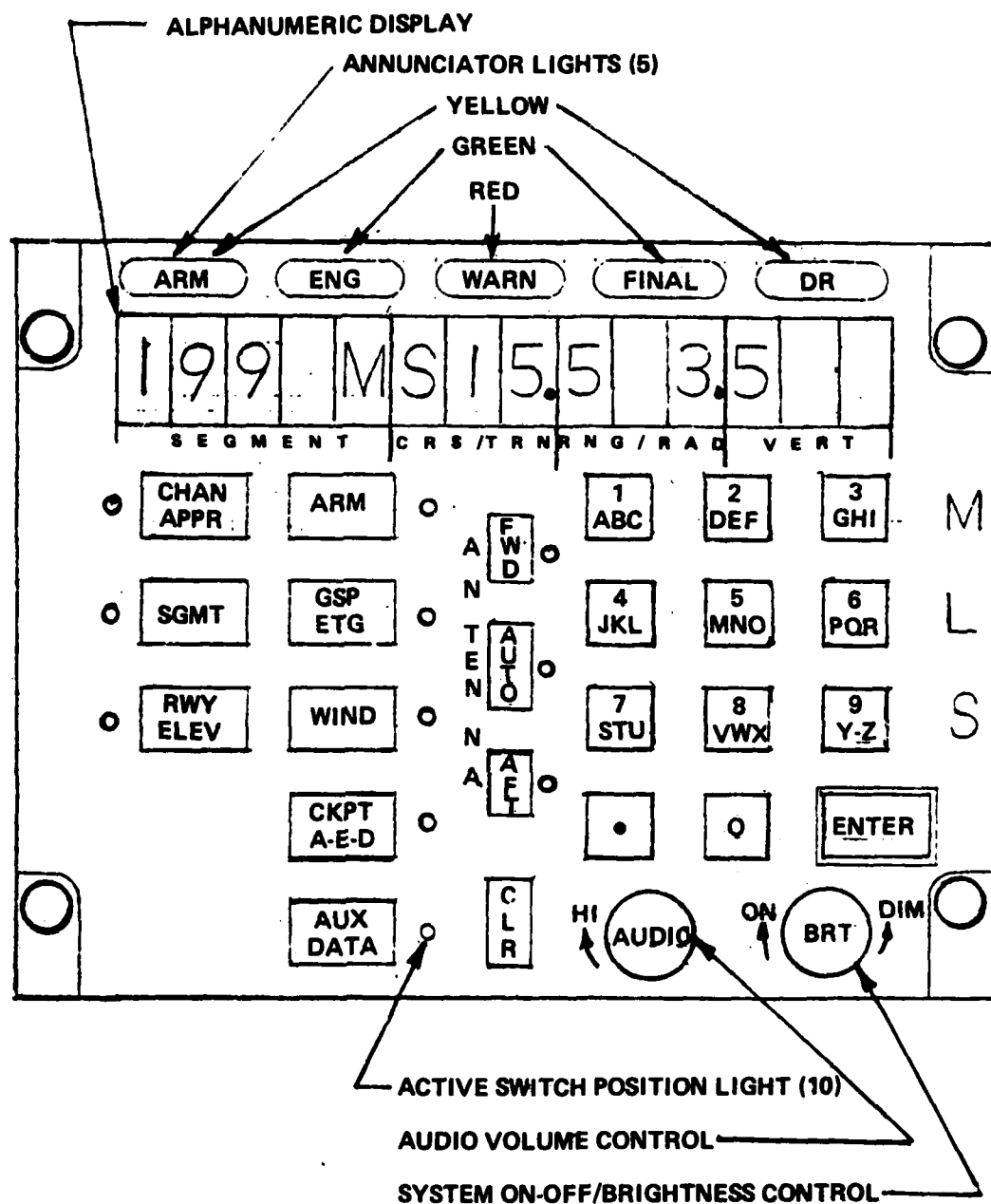


Figure 58 MLS CDU Candidate Number 2

PILOT ACTIVATED SW.	DISPLAY	COMMENTS
ON	ALL LIGHTS & TEST CHARACTERS ON FOR 2-3 SECONDS & THEN CHAN/APPR SW. ON C H A N A P P R	ANTENNA TO AUTO CHAN/APPR LIGHT ON
1	1 - A P P R	CURSOR (-) BLINKS AT NEXT INPUT LOCATION
9	1 9 - A P P R	
9	1 9 9 A P P R	
M	1 9 9 M -	
S	1 9 9 M S -	
1	1 9 9 M S 1 -	
5	1 9 9 M S 1 5.-	COMPUTER RECOGNIZES NEED FOR DECIMAL
5	1 9 9 M S 1 5.5 -	
3	1 9 9 M S 1 5.5 3 -	
.	1 9 9 M S 1 5.5 3.-	
5	1 9 9 M S 1 5.5 3.5	
ENTER	BLANK FOR 1/2 SECOND 1 9 9 M S 1 5.5 3.5	READ BACK FROM MEMORY
SGMT		CHAN/APPR LIGHT OUT COMPUTER SEARCHES FOR DATA ASSOCIATED WITH IDENT. & DISPLAYS HIGHEST SEGMENT. IF NO DATA
	S G M T C R S R N G V R T	
3	X - 3 - N A V V R T	CURSOR (-) BLINKS AT NEXT INPUT LOCATION
2	X - 3 2 - N A V V R T	

EXAMPLE OF CDU OPERATION
(GENERAL CASE)

AD-A096 593

BENDIX CORP TETERBORO N J FLIGHT SYSTEMS DIV

F/G 17/7

CONTROL-DISPLAY INVESTIGATION OF COMPLEX TRAJECTORY FLIGHT USIN--ETC(1)

DEC 79 R JOHNSTON, W MEDLINSKI, H SCHMIER

F33615-77-c-2053

UNCLASSIFIED

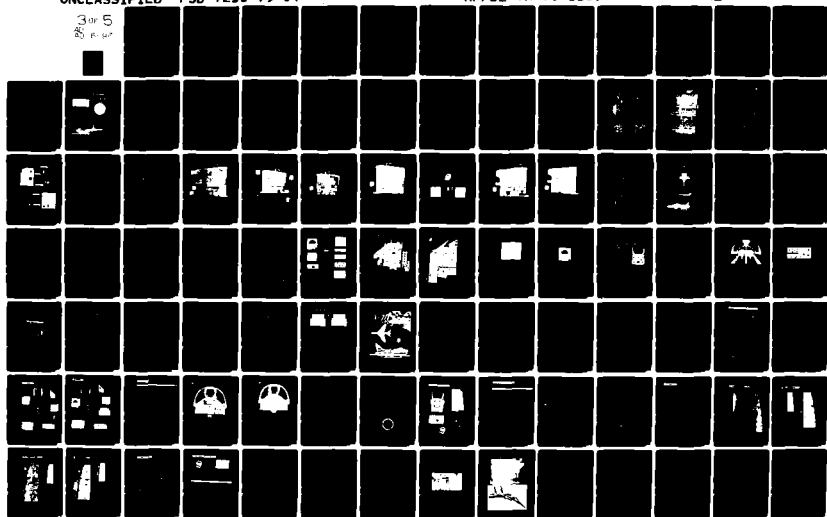
FSD-7211-79-04

AFFDL-TR-79-3139

NL

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80 8-107



PILOT ACTIVATED SW.		DISPLAY	COMMENTS
6	X - 3	2 6 - N A V V R T	
3	X - 3	2 6 3 N A V V R T	
0	X - 3	2 6 3 N A V 0.-	
ENTER		BLANK FOR ½ SECOND	
*SGMT	X - 3	2 6 3 N A V 0	READ BACK FROM MEMORY
	3 - 2		IF COMPUTER DID CONTAIN DATA NEXT INNER SEGMENT WOULD BE DISPLAYED
	3 - 2	-	
3	3 - 2	3 -	
0	3 - 2	3 0 -	
8	3 - 2	3 0 8 -	
3	3 - 2	3 0 8 3.-	COMPUTER RECOGNIZES 3 NOT 10s DIGIT & NEED FOR DECIMAL
0	3 - 2	3 0 8 3.0 -	
0	3 - 2	3 0 8 0. -	
ENTER		BLANK FOR ½ SECOND	
	3 - 2	3 0 8 3.0 0	READ BACK FROM MEMORY
*SGMT	2 - 1	-	
L	2 - 1	L F T C -	
1	2 - 1	L F T C 1 -	
.	2 - 1	L F T C 1.-	
0	2 - 1	L F T C 1.0-	
5	2 - 1	L F T C 1.0 5. -	COMPUTER RECOGNIZES 5 NOT 10s DIGIT & NEED FOR DECIMAL
0	2 - 1	L F T C 1.0 5.0	
ENTER		BLANK FOR ½ SECOND	

EXAMPLE OF CDU OPERATION
(GENERAL CASE) (CONTINUED)

PILOT ACTIVATED SW.		DISPLAY	COMMENTS
	2 - 1	L F T C 1.0 5.0	READ BACK FROM MEMORY
SGMT	1 - 0	-	
1	1 - 0	1 -	
2	1 - 0	1 2 -	
8	1 - 0	1 2 8 -	
4	1 - 0	1 2 8 4.-	COMPUTER RECOGNIZES 4 NOT 10s DIGIT & NEED FOR DECIMAL
0	1 - 0	1 2 8 4.0 -	
3	1 - 0	1 2 8 4. 3.-	COMPUTER RECOGNIZES 3 NOT 10s DIGIT & NEED FOR DECIMAL
ENTER	BLANK FOR $\frac{1}{2}$ SECOND		COMPUTER ASSUMES 0
	1 - 0	1 2 8 4.0 3.0	READ BACK FROM MEMORY
RWY ELEV	R W Y	E L E V -	SGMT LIGHT OUT
7	R W Y	E L E V 7 -	
6	R W Y	E L E V 7 6 -	
ENTER	BLANK FOR $\frac{1}{2}$ SECOND		
	R W Y	E L E V 7 6	READ BACK FROM MEMORY
CKPT A•E•D	3 5 0°	4.1° 1 7.1 NM	RWY ELEV LIGHT OUT
ARM	3 5 0°	4.1° 1 7.1 NM	ARM ANNUNCIATOR ON

EXAMPLE OF CDU OPERATION
(GENERAL CASE) (CONTINUED)

4.3.3 CDU Candidate Number 3

Another alternate CDU configuration which minimizes pilot workload, when manual data entry is required, is shown in Figure 59. Similar to the previous CDU, this design can be used to define a wide variety of trajectories from the most simple straight-in approach to the most complicated trajectory, consisting of several lateral and vertical segments. It is considered to have advantages over both previous CDU candidates since it combines the virtues of minimizing entries while at the same time utilizing common pilot terminology for the displayed data requirements and control actuations. The overall system design is applicable to both a CRT-type CDU and a discrete alphanumeric segment CDU. It differs from the previous designs in the following ways:

1. Data is displayed in a vertical "page" format instead of a horizontal "line" format.
2. More data can be read out per control actuation.
3. Operation is easier.
4. Cost is higher.

The philosophy of this CDU for trajectory definition, MLS mode selection, and data readout is very similar to the previous designs. The main difference is that a distinction is made between lateral and vertical segments and that the number of lateral and vertical segments of this trajectory must be immediately defined to the computer following MLS channel selection. With this information, the computer can sequentially direct the pilot entering the required data to totally define and check the desired approach.

The "pages" of information to be entered and displayed are defined in Table 7. These pages appear automatically as the pilot enters data in the normal sequence, or they can be called up manually if the pilot wishes to alter data. Ground speed/wind speed and auxiliary data pages can also be called up by actuation of their respective pushbuttons. It should be noted that only three lateral segment pages are shown. This was done to allow comparison with the first CDU design discussed. For the CDU Candidate Number 3 design, however, a limitation in trajectory segments

does not exist.

A description of the data and pushbutton mnemonics is contained in Tables 8 and 9, respectively.

Descriptions of typical pilot procedures for entering, checking and altering trajectory data follow. The data entered is based on the approach path shown in Figure 60.

Data Entry Procedure

I. Depress DEF APPR pushbutton

II. Page 1 appears with last entered approach data.

- A. CHAN mnemonic flashed if not CRT, cursor flashes under number if CRT (for rest of procedure non-CRT CDU is assumed).
- B. Insert MLS channel of runway = 182 ("inserting" data involves keying in desired value and depressing ENTER pushbutton).
- C. APPR mnemonic flashes.
- D. Insert approach number and direction = 422L
 - 1. If approach number is in memory, HDG and ELV will replace LSEG and VSEC, respectively.
 - a. HDG mnemonic flashes.
 - b. Insert runway heading = 000.
 - c. ELV mnemonic flashes.
 - d. Insert runway elevation above sea level = 156.
 - e. Profile entry is complete.
 - f. Page 1 remains for 3 sec., then automatically advances to Approach Check Point Page.

- g. Insert check point along track distance = 8.0.
 - h. Display automatically advances to Check Point Data Page.
 - i. Pilot verifies check point azimuth, altitude and DME data on CDU versus that on approach plate.
 - 2. If approach number is not in memory, LSEG mnemonic flashes
 - a. Insert number of lateral segments = 3
 - b. VSEG mnemonic flashes
 - c. Insert number of vertical segments = 2
- III. Page 1 remains for 3 seconds, then automatically advances to Page 2 (RWY DATA) if approach number not previously in memory.
 - a. HDG mnemonic flashes
 - b. Insert runway heading = 000
 - c. ELV mnemonic flashes
 - d. Insert runway elevation above sea level = 156
- IV. Page 2 remains for 3 seconds, then automatically advances to Page 3 (LAT SEG 1)
 - a. DIST mnemonic flashes
 - b. Insert final approach length = 4.2
 - c. RAD mnemonic flashes
 - d. Insert radius of turn on to final = 1.0
- V. Page 3 remains for 3 seconds, then automatically advances to Page 4 (LAT SEG 2).

- VI. This procedure continues until all data has been entered and the profile data entry has been checked via the check point. Data will appear on each page as in Table 7.

If the automatic checkpoint test fails or if the entered data must be altered slightly due to a change in traffic control clearance, a means of manually sequencing through the approach definition data is required. The procedure for this operation involves:

- I. Depressing CHK APPR pushbutton.
- II. Sequencing through the pages of definition data by repeatedly depressing the ADV PAGE pushbutton.
- III. Checking the data until the error, or the parameter desired to be changed, is reached.
- IV. Depressing the ADV LINE pushbutton until the mnemonic of the erroneous value is flashing.
- V. Inserting the correct, or new, value.

Use of the other pushbuttons, annunciator lights and switches is similar to that described for CDU Candidate Numbers 1 and 2.

			MLS													
<div>○</div> <div>ARM</div> <div>ENG</div> <div>FINL</div> <div>○</div>	1	2	3	C	H	A	N		1	8	2		<div>○</div> <div>WARN</div> <div>DR</div> <div>AUTO</div> <div>○</div>			
	4	5	6	A	P	P	R		4	2	2	L				
	7	8	9	L	S	E	G		3							
	•	0	L/R	V	S	E	G		2							
			DEF APPR		ENTER				FWD		ARM		WSP GSP		AUX DATA	
			CLR		CHK APPR		ANTEN									
			ADV PAGE		ADV LINE		AFT		HI		AUDIO		ON		BRT	
													DIM			

Figure 59 MLS CDU Candidate Number 3

TABLE 7

CDU Candidate Number 3 -- Pages of Information

PAGE 1

CHAN 182
APPR 422L
LSEG 3
VSEG 2

PAGE 2

RWY DATA
HDG 000
ELV 156

PAGE 3

LAT SEG 1
DIST 4.2
RAD 1.0

PAGE 4

LAT SEG 2
DIST 3.0
CRS 045

PAGE 5

LAT SEG 3
CRS 030

PAGE 6

VRT DATA
GSI 3.0
ALT 1000
GS2 5.0

PAGE 7

APP CHK PT
DIST 8.0

PAGE 8

CHK DATA
AZ 15.6 L
ALT 3739
DME 9.4

PAGE 9

(GROUND SPD/WIND SPD)
GSP 145
WSP 12
WBG 210
ETG 1.2

PAGE 10

(TYPICAL AUX DATA)

TABLE E
CDU Candidate No. 3 Data Mnemonics

<u>MNEMONIC</u>	<u>DEFINITION</u>	<u>RANGE</u>	<u>UNITS</u>
CHAN	MLS Channel Number	0-200	-
APPR	MLS Approach Number L=from left of runway centerline R=from right of runway centerline	0-999	-
LSEG	Number of Lateral Segments	1-9	-
VSEG	Number of Vertical Segments	1-2	-
RWY DATA	Runway Data Page	-	-
HDG	Runway Heading	000-359	Degrees
ELV	Runway Elevation	0-9999	Feet
LAT SEG 1	Lateral Segment #1 Page	-	-
LAT SEG 2	Lateral Segment #2 Page		
LAT SEG 3	Lateral Segment #3 Page		
DIST	Length of Segment	0-99.9	Nautical Miles
RAD	Radius of Turn on to Segment	0-9.9	Nautical Miles
CRS	Course of Segment	000-359	Degrees
VRT DATA	Vertical Data Page	-	-
GSI	Final Approach Glide Path Angle	1.0-9.5	Degrees
ALT	Glide Path Transition Attitude	000-9999	Feet
GS2	Initial Glide Path Descent Angle	0-20.0	Degrees
APP CHK PT	Approach Check Point Page	-	-
DIST	Check Point Along Track Distance from Touchdown	0-99.9	Nautical Miles

<u>MNEMONIC</u>	<u>DEFINITION</u>	<u>RANGE</u>	<u>UNITS</u>
CHK DATA	Check Point Data Page	-	-
AZ	MLS Azimuth Angle of Check Point L=left of runway centerline R=right of runway centerline	0-60.0	Degrees
ALT	Check Point Altitude	0-20,000	Feet
DME	Check Point DME	0-30.0	Nautical Miles
GSP	Ground Speed	0-999	Knots
WSP	Windspeed	0-999	Knots
WBG	Wind Bearing	000-359	Degrees
ETG	Estimated Time-to-Go to Touchdown	0-99.9	Minutes

CDU Candidate No. 3 Data Mnemonics
TABLE 8 - Continued

TABLE 9
CDU Candidate No. 3 Pushbutton Mnemonics

<u>PUSHBUTTON</u>	<u>DEFINITION</u>	<u>ACTUATION RESULTS</u>
DEF APPR	Define Approach	Activates automatic sequencing through pages as data is entered.
CHK APPR	Check Approach	Allows manual sequencing through pages to check and/or modify data.
ADV PAGE	Advance Page	Causes advancement to next page of data.
ADV LINE	Advance Line	Causes uppermost mnemonic on page to flash. Repeated depression advances flashing to mnemonic of next lower line of data.
ENTER	Enter Data	Data inserted is entered into computer memory.
CLR	Clear	Causes reversion back to previous data if depressed with mnemonic flashing.
ARM	Arm	Arms MLS mode for engagement.
AUX DATA	Auxiliary Data	Calls up auxiliary data information. Repeated actuation causes sequencing through several auxiliary data pages.

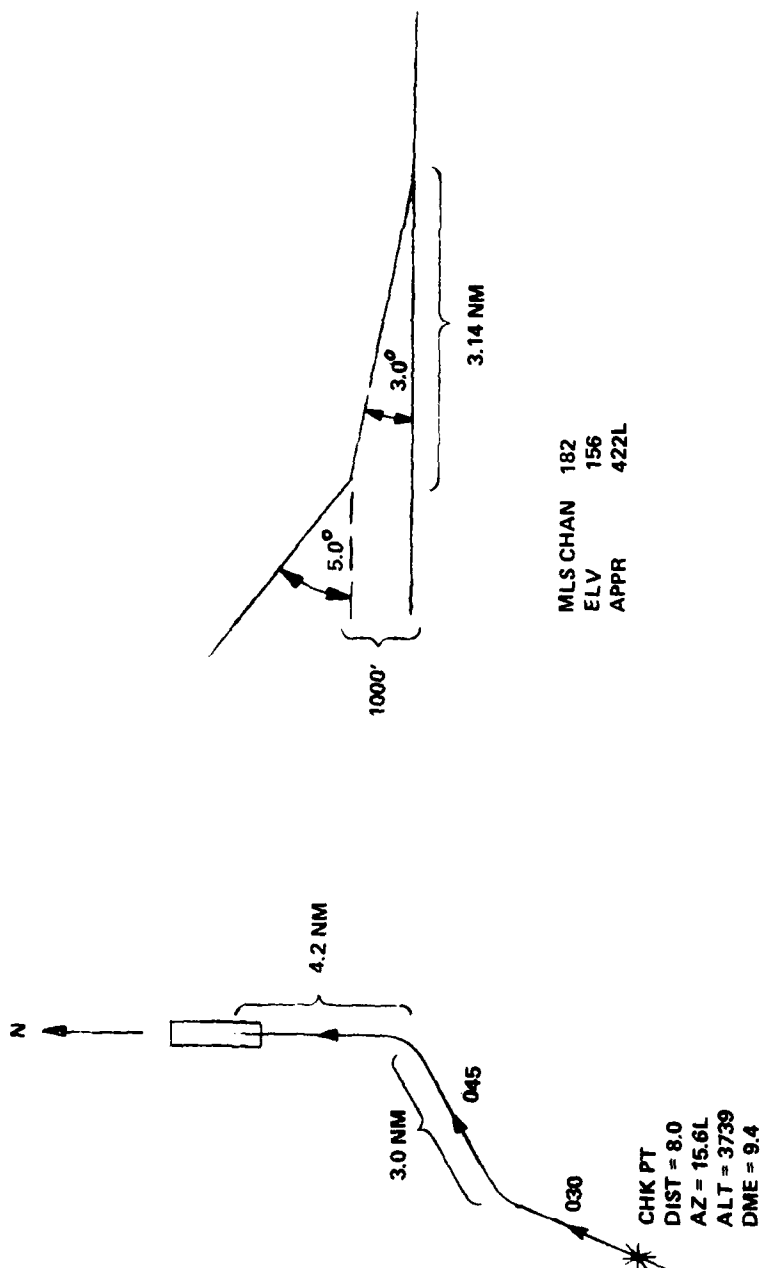


Figure 60 Approach Path Example For CDU Candidate No. 3

5.0 RETROFIT OF MLS INTO EXISTING USAF AIRCRAFT

5.1

Summary of Aircraft Studies

In this section, study results are presented for five aircraft which were chosen to represent a cross-section of the USAF inventory. These aircraft are the C-130A/D; F-111A/E; A-7D; F-15A; and KC-10A. For the first four of these aircraft, Technical Orders on the pertinent systems were obtained from the Air Force Flight Dynamics Laboratory. Since no T.O.'s exist, as yet, on the KC-10, information on this aircraft was obtained directly from the Douglas Aircraft Company Division of the McDonnell-Douglas Corporation.

The studies consisted of a review of the basic aircraft systems which would be logically affected by the integration of MLS; and then, an adaptation of one of the four general MLS configurations defined in Section 4.1 which the analysis tended to recommend. No detailed analysis was made of mission requirements, space or weight limitations since this was considered to be outside the scope of this study. No tradeoffs were conducted to determine if MLS computations were more cost-effectively incorporated in an existing computer or a new computer. The recommended MLS configuration for each aircraft was based on the control-and-display capabilities of that aircraft and the anticipated pilot workload levels to perform the various levels of complex trajectory flight.

The studies resulted in the following recommendations:

<u>AIRCRAFT</u>	<u>RECOMMENDED MLS CONFIGURATION</u>
C-130A/D	MLS-1 (DIRECT ILS REPLACEMENT)
F-111A/E	MLS-1 (DIRECT ILS REPLACEMENT)
A-7D	MLS-3 (SELECTABLE INTERCEPT OF FINAL)
F-15A	MLS-3 (SELECTABLE INTERCEPT OF FINAL)
KC-10A	MLS-4 (COMPLEX TRAJECTORY)

MLS CONSIDERATIONS

T.O. 1C-130A-1

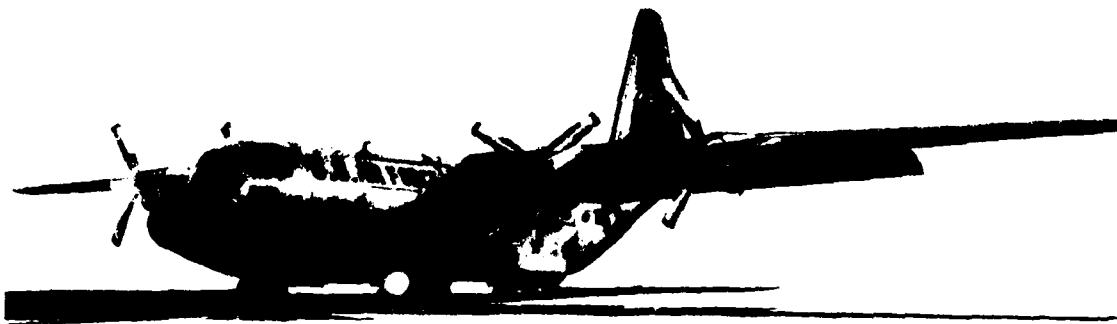
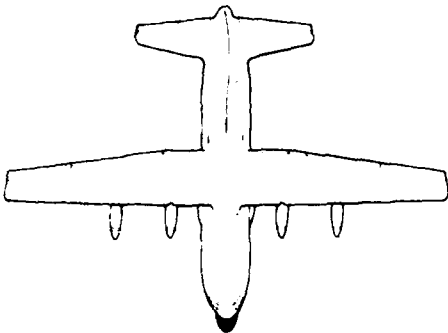


the airplane

**C-130A AND
C-130D-6**



Hercules



130A-1-33-002-1

v

5.2 C-130A/D

5.2.1 General/C-130A/D Information

The Lockheed C-130 is a high-wing, all-metal construction, medium-range, land-based monoplane. The mission of the airplane is to provide rapid transportation of personnel or cargo for delivery by parachute or landing. The airplane can be used as a transport carrying 92 ground troops or 64 paratroops and equipment, and can be readily converted for ambulance or aerial delivery missions. The C-130 can land and take off on short runways and can be used on landing strips such as those usually found in advance base operations.

A block of the C-130 airplanes was modified to add skis and designated as C-130D. A part of the C-130D fleet has skis removed, and these airplanes are designated C-130D-6.

Crew stations are provided for a pilot, copilot, flight engineer, and navigator. The pilot and copilot are seated on left and right sides, respectively, of the control pedestal in the forward section of the flight station. The navigator is seated behind the copilot on the right side of the flight station, facing outboard. The flight engineer is seated in the center of the flight station, behind the pilot and copilot.

Presently, ILS approaches can be made only by certain aircraft, utilizing either the flight director or autopilot. Flight Directors are not installed on all C-130 aircraft, and the autopilot is inoperative on some aircraft (see T.O. IC-130A-2-1, Page 9-42, Section 9-57).

The flight director system provides roll steering commands to the ADI for localizer path control. When the ILS mode is selected, the miniature aircraft on the ADI is slaved to a 2.5° preset position above the horizon bar. This is the extent of the glide path control.

Autopilot coupled approaches must be continuously monitored (see T.O. IC-130A-1, Page 4-94, Normal Autopilot Operation); and, with the exception of ILS, the autopilot should be disengaged below 1,000 ft.

Since all C-130 aircraft utilize only single LOC/VOR and Glide Slope receivers and because of autopilot and flight director deficiencies, the C-130 has a category I approach system.

Integration of an MLS system into the C-130 aircraft involves consideration of existing navigation equipment (units or systems) which can be time shared or modified. The following is a list of this equipment.

<u>TYPE</u>	<u>QTY.</u>	<u>DESIGNATION</u>
Radio Compass	2	AN/ARN-6
LOC/VOR Receiver	1	AN/ARN-14
Tacan	1	AN/ARN-21
Glide Slope Receiver	1	AN/ARN-18 or -31
Direction Finder	1	AN/ARN-25
*Talar System	1	AN/ARN-97
Indicator (Deviation)	1	ID-48/ARN or ID-525 ARN
Indicator (Deviation)	1	ID-249/ARN
Indicator (RMI)	5	ID-250/ARN
Indicator, Azimuth	1	ID-307/ARN
Indicator, Range	1	ID-310/ARN
Autopilot	1	E4
Beam Guidance Coupler	1	MB-4
*Flight Director System:	1	MA-1
Gyro Monitor	1	327B-2
Approach Horizon	1	329B-3
Course Indicator	1	331A-3
Vertical Gyro	1	332D-6
Steering Computer	1	562A-3B

* Not installed on all aircraft.

Some aircraft have TALAR systems installed which receive low level microwave signals and process them into steering and deviation signals for use as a landing approach aid. If TRSB MLS is installed on USAF aircraft, it is expected that the TALAR system will be removed.

Some aircraft utilize an MA-1 flight director system which substitutes an HSI and ADI for the pilot's ID-249 (deviation indicator).

Five ID-250 (RMI) Indicators and an ID-307 (Azimuth) Indicator are used to present bearing information. Three ID-250 instruments are dedicated to the ARN-6 radio compass system. The No. 2 pointers of the other two ID-250 instruments can be switched via the TAC/VOR/ILS switch to the respective navigation references. The ID-307 (single pointer) is dedicated to Tacan.

The TAC/VOR/ILS switch controls relays which transfer the audio, bearing and deviation signals of the various navigation references to the appropriate elements. Tacan range signals are applied directly to a pilot's indicator.

A block diagram of the existing navigation system is illustrated in Figure 61. Only those elements involved with the MLS installation or possible MLS usage are shown. Although the existing installation includes an independent doppler system which utilizes a dedicated computer, controls and instruments, none of these is adaptable for MLS. The block diagram also shows the functions which must be interrupted and switched to install the recommended direct ILS replacement MLS-1 configuration (see Section 4.1). Details explaining this recommendation follow.

5.2.2 C-130A/D MLS Recommendations

Since only single LOC/VOR and Glide Slope receivers are used on the studied C-130-A and -D aircraft, the low approach system is Category I. Furthermore, due to the age of the aircraft, the present autopilot is of an early vintage and is not recommended for use below 1,000 ft. unless the controls are continuously monitored. Although certain aircraft have an MA-1 flight director system installed, only localizer (lateral) flight path steering control is provided. No glide slope flight path steering is available. At glide slope engagement, the pitch

steering bar is displaced to command the 2.5° nose-down attitude needed to maintain the glide path. Crude path control is maintained by keeping the pitch steering bar opposite the glide slope deviation indicator.

Like the autopilot and flight director systems, the display technology included in these aircraft is also of a primitive nature. Many individual indicators are provided throughout the cockpit with very little display integration.

Based on the above considerations, only the MLS-1 configuration (direct ILS replacement) is recommended for the C-130-A or -D aircraft. If the complex trajectory, MLS-3 and MLS-4, configurations are to be considered, the following avionics improvements must be made:

1. Update present autopilot and/or add modern flight director system.
2. Replace present ID-249 or HSI (flight director system) with an HSI which allows remote slewing of the course carriage and pointer.

Installation of a minimum MLS-1 configuration (see Figure 38 Block Diagram, MLS-1) in this type aircraft involves the addition of the following units:

<u>UNIT</u>	<u>QUANTITY</u>
MLS Angle Receiver	1
MLS Switching Unit	1
MLS-1 Tuner	1
MLS Angle Antenna	1

Because the C-130-A or -D aircraft mission involves usage at forward operating bases, where marker beacons may not be provided, it is also recommended that the MLS DME system be installed. This requires the following additional units:

<u>UNIT</u>	<u>QUANTITY</u>
MLS DME Interrogator	1
Digital-to-Analog Converter	1
MLS DME Antenna	1

The first two units in each grouping can be remotely located. Ample room is available on the existing radio racks to accommodate these units (see Figure 62).

Space is available on the existing overhead panel (see Figure 63 lower right) to accommodate the MLS-1 tuner.

The MLS angle and DME antennas can be mounted on the underside of the nose of the aircraft (see Figures 64 and 65), aft of the radome, just forward of the access door.

The instrument select switch is used to select the desired navigational reference. When a particular reference is selected, relays in the radio junction box transfer the proper audio reference to the VHF NAV on-off switch (see Figure 66, lower right). Since MLS signals will be substituted for the present ILS signals when the MLS mode is selected, the present VHF NAV switch provides the interface to the audio system. Therefore, an MLS audio on-off switch is not required. Volume control is provided by a knob on the MLS-1 tuner.

Holes exist on the radio junction box panels to accommodate the MLS system circuit breaker. Figure 67 shows a typical location for aircraft utilizing an MA-1 flight director. For installations without the MA-1 system, six holes are available at the same location.

The following is a brief description of the existing instruments available for MLS (time-shared) usage. In addition, the type of interface required by each instrument is discussed and the location of each instrument is pin-pointed.

ID-249 Deviation Indicator (see Figure 68, Panel B)

This instrument is installed only on aircraft which do not utilize the MA-1 flight director system. It includes the same functions as the ID-48/ID-525 unit and, in addition, displays deviations from a pre-set course which is selected by a knob on the front of the instrument. A numerical readout is provided for setting the pre-set course. Coupled to the pre-set course selector shaft is a synchro which supplies pre-set course deviation to the autopilot coupler for flight path control computations.

This instrument must interface with analog and discrete signals. Thus, it is only compatible with the raw data outputs of the

MLS system. Since the pre-set course indicator and readout are not remotely-sleuable, aircraft with this instrument can only accept the MLS-1 configuration.

The ID-249 instrument is located on the pilot's instrument panel and is shown on Figure 69, Ref. No. 5.

ID-48/ID-525 Deviation Indicator (see Figure 68, Panel A).

The ID-48 and ID-525 Indicators are interchangeable and either one can be installed on the C-130 aircraft. The indicator is used to display lateral and longitudinal deviations from navigational references and also includes on-off flags to display the validity of these references. Lateral deviations (LOC, VOR and Tacan) are displayed on the vertical needle and longitudinal deviations (glide slope) are displayed on the horizontal needle.

This instrument must interface with analog and discrete signals. Accordingly, it is only compatible with the raw data outputs of the MLS system.

The ID-48/ID-525 instrument is located on the copilot's instrument panel and is shown on the Figures 70 and 71 (Ref. No. 5) and Figure 72, Ref. No. 34.

331A-3 Course Indicator (See Figure 67, Panel D)

The course indicator (HSI) is part of the MA-1 flight director system (see Figure 73). This instrument provides a display consisting of a compass card, course deviation indicator and a pre-set course indicator. The deviation indicator is used to display lateral deviations from a navigational reference. A knob is provided for positioning the pre-set course bug relative to the compass card. A synchro is connected to the shaft end of the knob and it provides preset course deviations to the flight director and autopilot couplers.

This instrument must interface with analog signals and accordingly is only compatible with the raw data outputs of the MLS system. Furthermore, the course carriage and pre-set course indicators are not remotely sleuable; therefore, the present installation is not compatible with the MLS-3 and MLS-4 configurations. A replacement instrument must be used if MLS-3 or MLS-4 approach performance is required.

The 331A-3 HSI is located on the pilot's instrument panel and is shown on Figures 74 Ref. No. 32 and 104, Ref. No. 6.

329B-3 Attitude Direction Indicator (See Figure 67
Panel D)

The attitude direction indicator (ADI) is part of the MA-1 flight director system (see Figure 73). This instrument provides a display consisting of glide slope deviation indicator, glide slope and localizer validity flags, attitude references and a bank steering. The bank steering bar is used during ILS approaches for localizer flight path control. No flight path control for glide slope (pitch steering) is available.

This instrument must interface with analog and discrete signals. Thus, it is only compatible with the raw data outputs of the MLS system.

The 329B-3 ADI is located on the pilot's instrument panel and is shown in Figures 74, Ref. No. 34 and 104, Ref. No. 8.

ID-310 Range Indicator (See Figure 75, Panel E)

This instrument provides a numerical readout of range (kts) to station and is presently dedicated to the Tacan system. Since its interface is analog and since range is only available in digital form from the MLS system, the display is not directly compatible with MLS. To provide compatibility, a digital-to-analog converter unit is required.

The ID-310 instrument is located on the pilot's instrument panel and is shown on Figures 69 and 74, Ref. No. 13, and 104 Ref. No. 16.

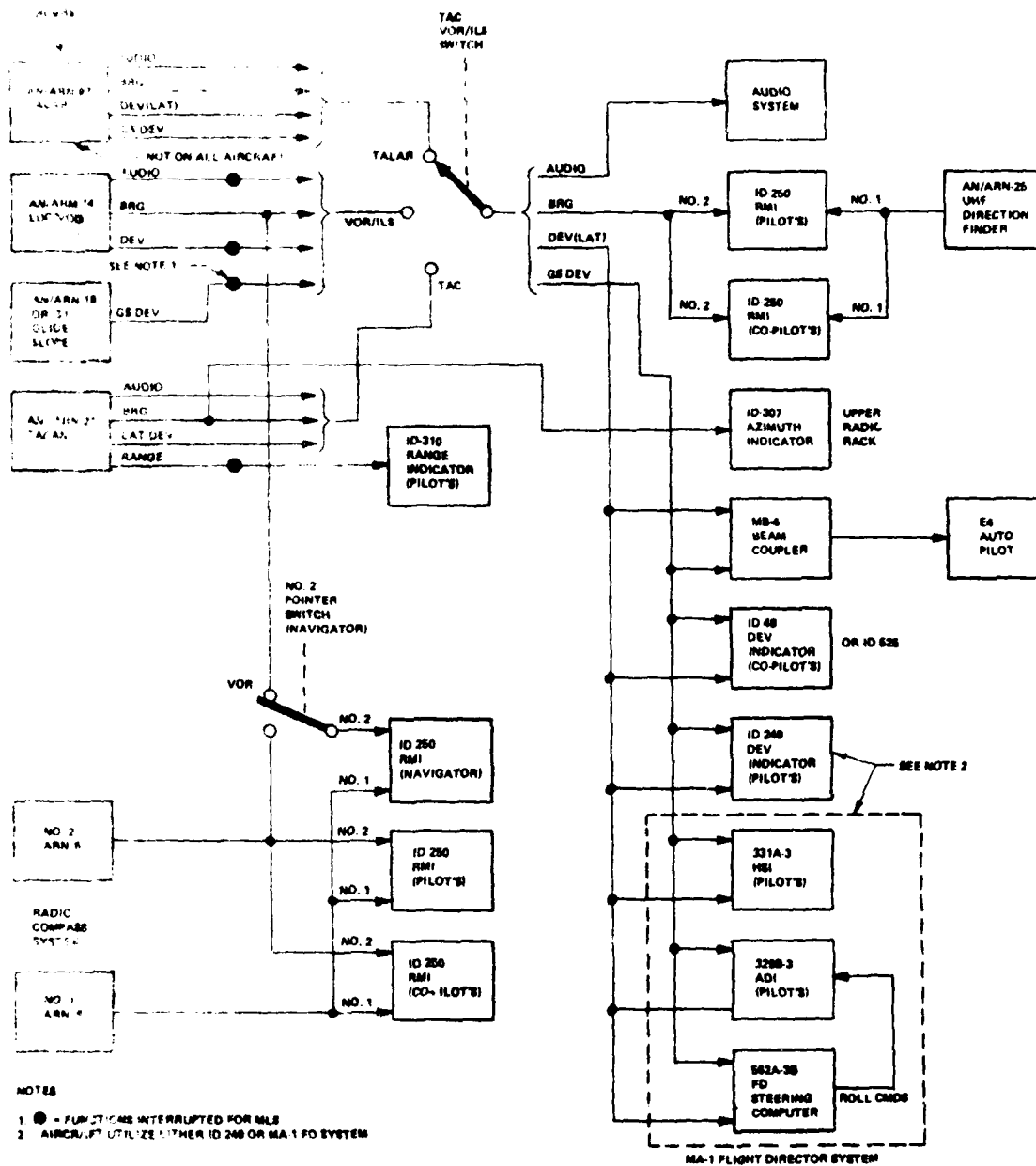


Figure 61 Block Diagram C130A & C130D-6 Navigation System

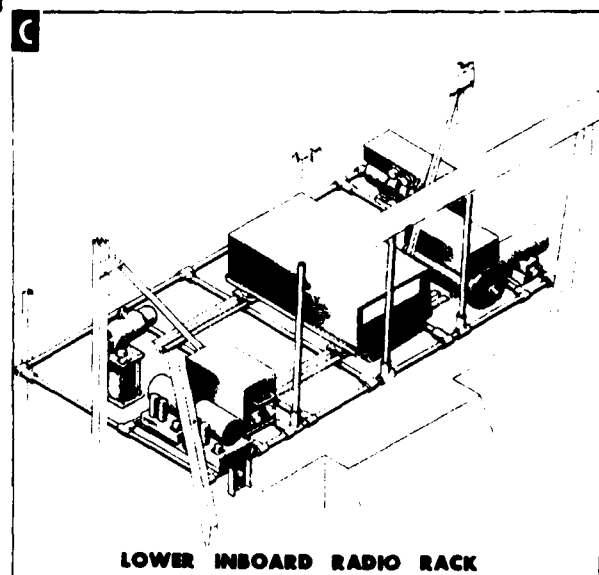
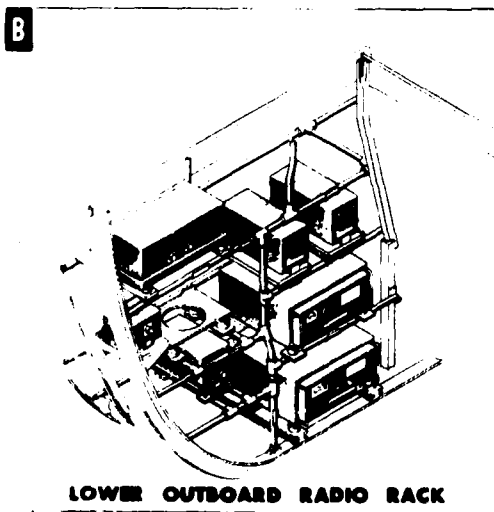
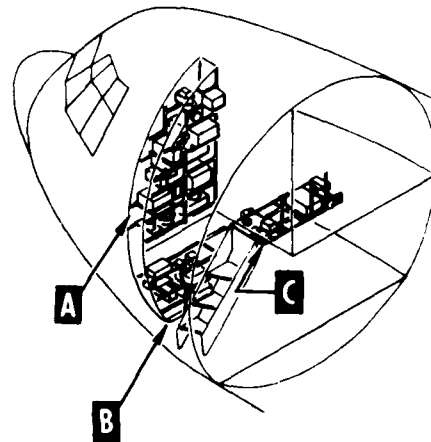
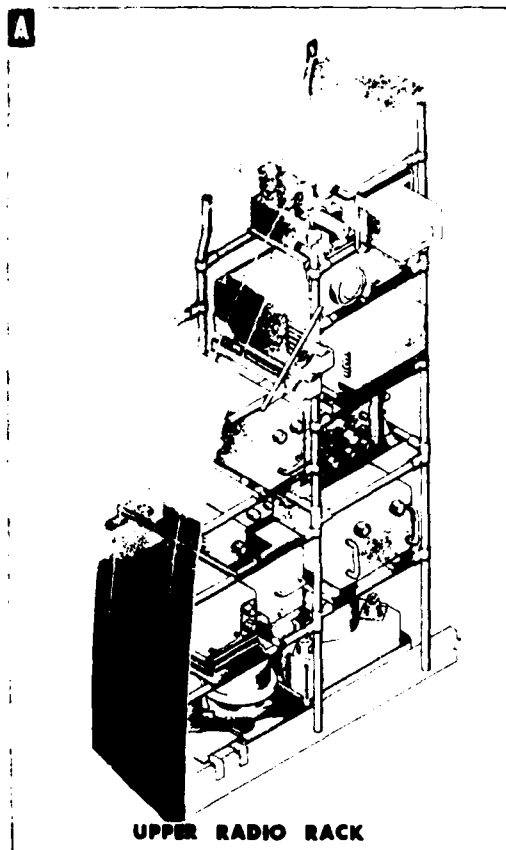
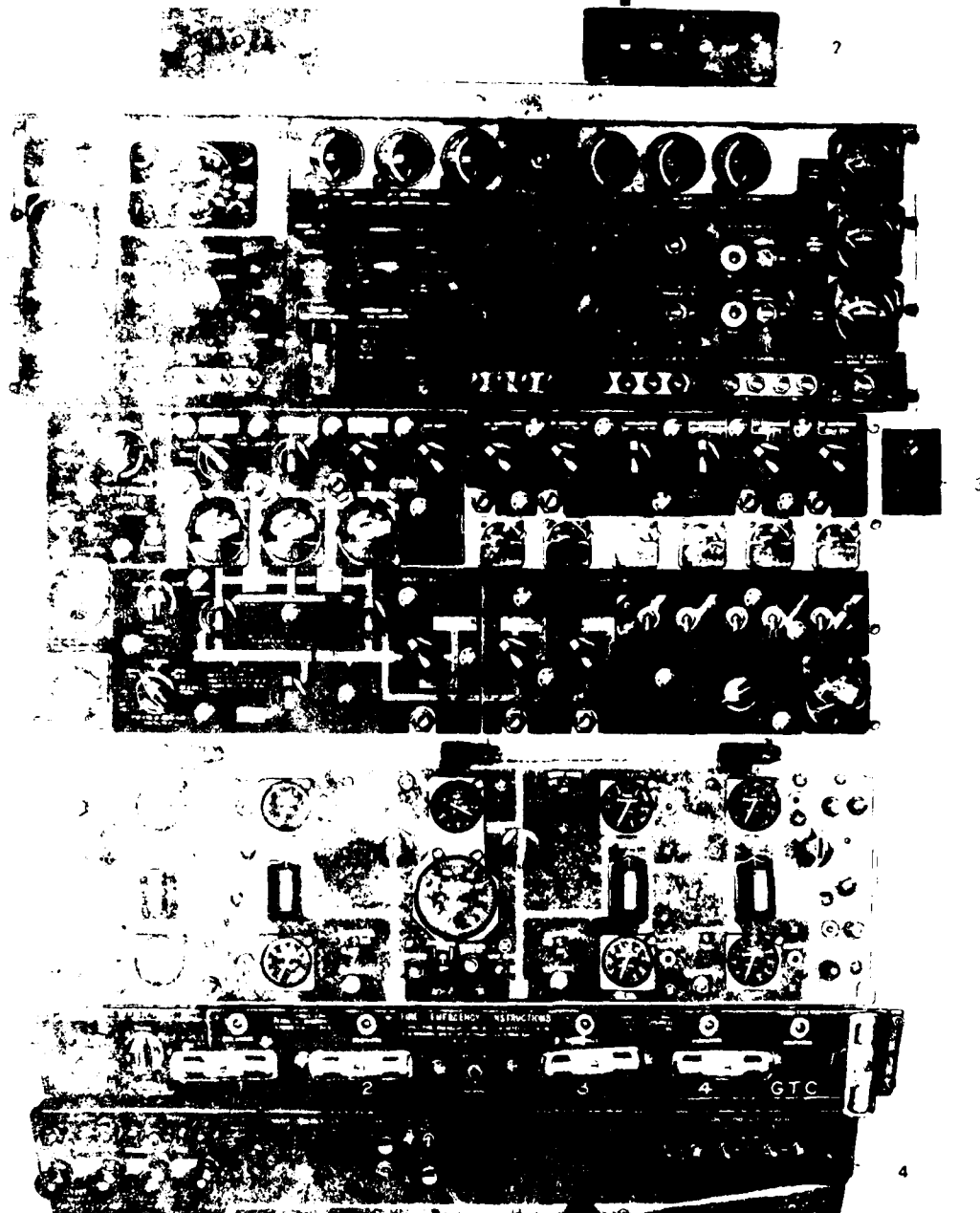


Figure 62 Radio Racks Location

overhead control panel

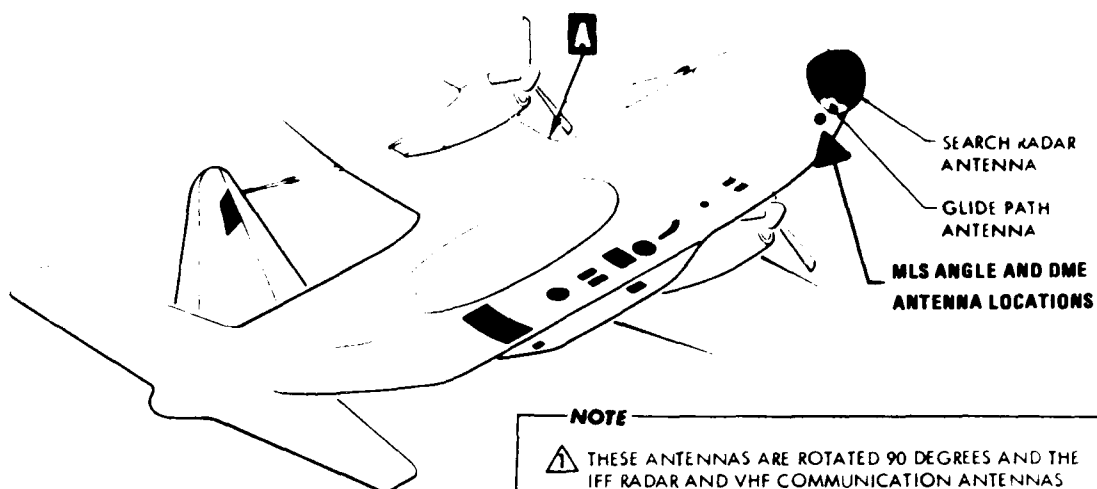


1. ANTICOLLISION TEST PANEL
2. FUEL INDICATING PANEL
3. FUEL INDICATING PANEL
4. GTC DOOR FLAPS SWITCH PANEL
5. GTC DOOR DETECTION PANEL
6. GTC DOOR DETECTION PANEL
7. GTC DOOR DETECTION PANEL
8. GTC DOOR DETECTION PANEL
9. FUEL CONTROL PANEL
10. ELECTRICAL CONTROL PANEL
11. GTC DOOR SWITCH AND LIGHT (SOME AIRPLANES)
12. AIR CONDITIONING CONTROL PANEL

AVAILABLE SPACE

130A-33-007

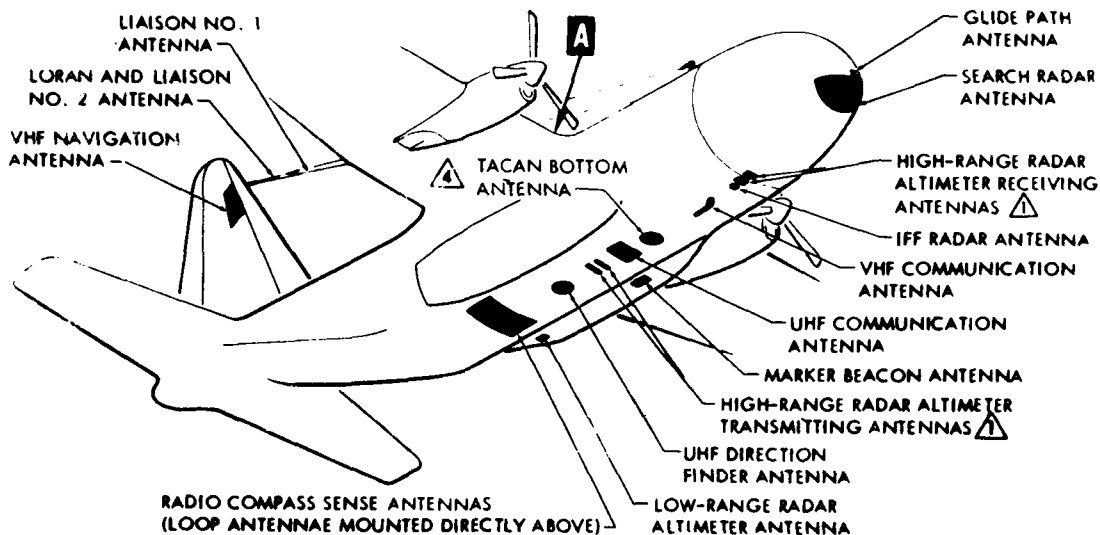
Figure 1. Overhead Control Panel



**AIRPLANES AF55-001 THROUGH
55-020, 55-022 THROUGH 57-483,
AND 57-496 AND UP**

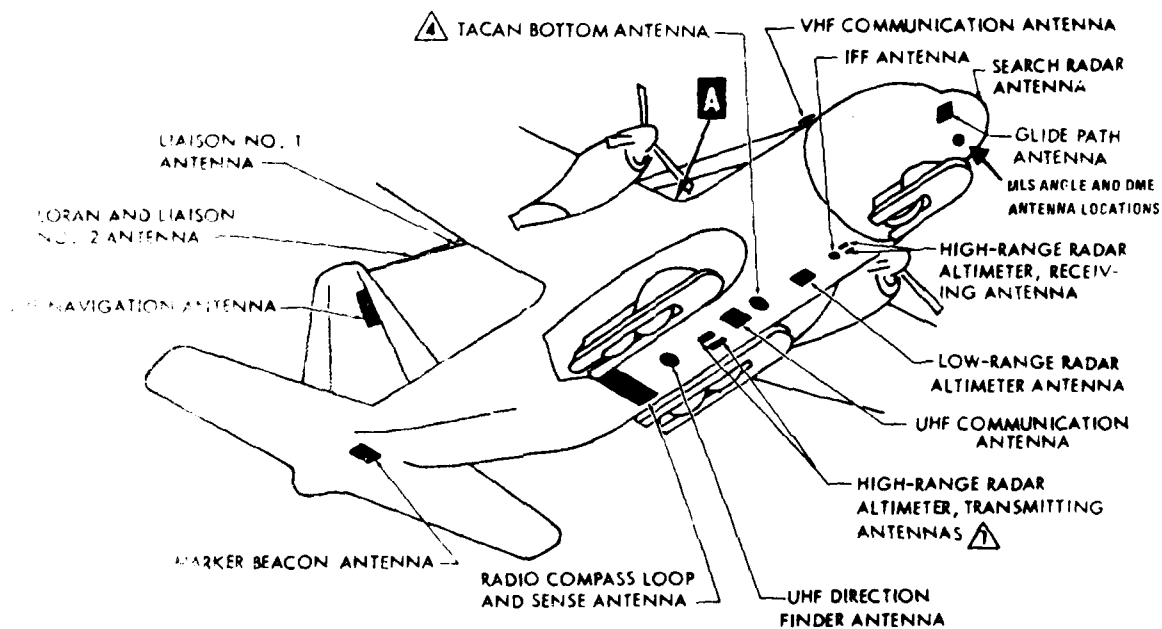
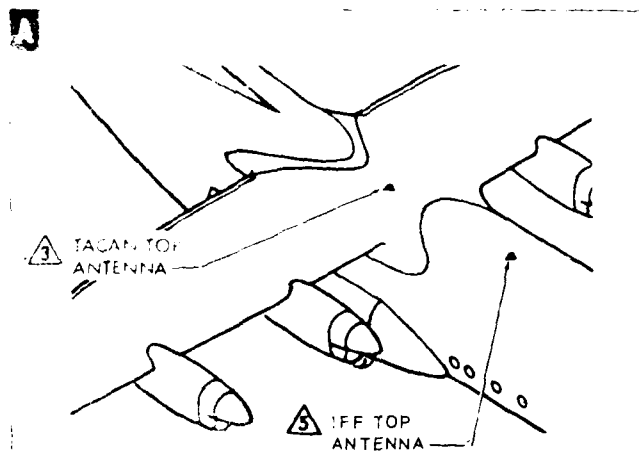
NOTE

1. THESE ANTENNAS ARE ROTATED 90 DEGREES AND THE IFF RADAR AND VHF COMMUNICATION ANTENNAS ARE MOVED AFT 20 INCHES ON AIRPLANES AF54-1635 THROUGH 54-1640.
2. ALL ANTENNA LOCATIONS SHOWN ABOVE ARE THE SAME AS THOSE SHOWN BELOW, EXCEPT AS NOTED.
3. AIRPLANES AF53-3129 THROUGH 57-509 IF MODIFIED BY T.O. 1C-130-538.
4. AIRPLANES AF52-3129 THROUGH 56-551 IF MODIFIED BY T.O. 1C-130A-659, 57-453 THROUGH 57-509 IF MODIFIED BY T.O. 1C-130A-757, AND 57-510 AND UP.
5. AIRPLANES MODIFIED BY T.O. 1C-130-838.



AIRPLANES AF53-3129 THROUGH 53-3135, AND 54-1621 THROUGH 54-1640

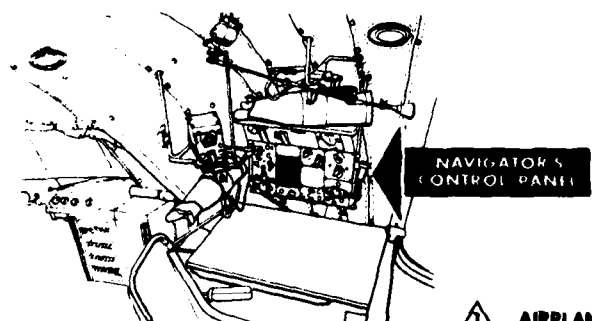
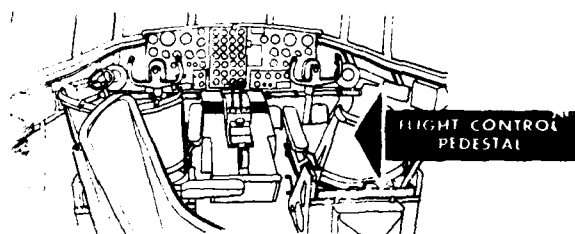
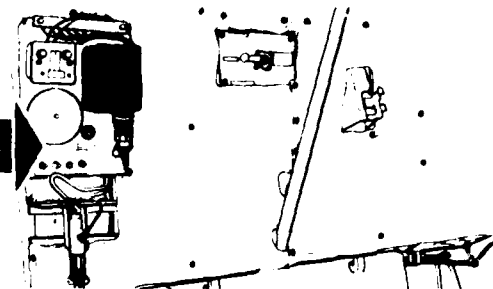
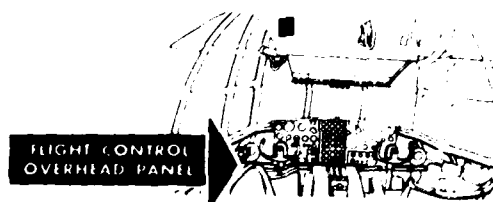
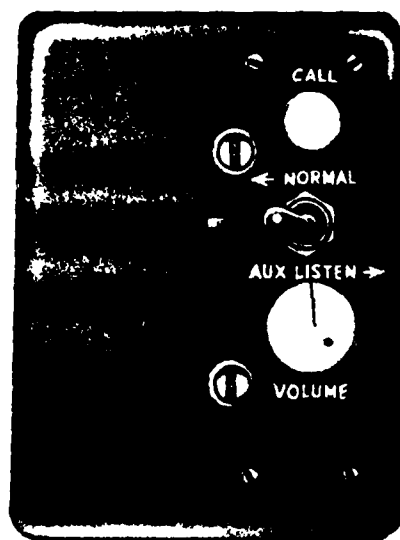
Figure 64 Antenna Locations



Airplanes AF55-021 and 57-484 through 57-495

Figure 64 Antenna Locations (cont'd)

intercommunication controls



⚠ AIRPLANES MODIFIED BY T.O. 1C-130A-793 130A-1-33-109-1

Figure 66 Intercommunication Control

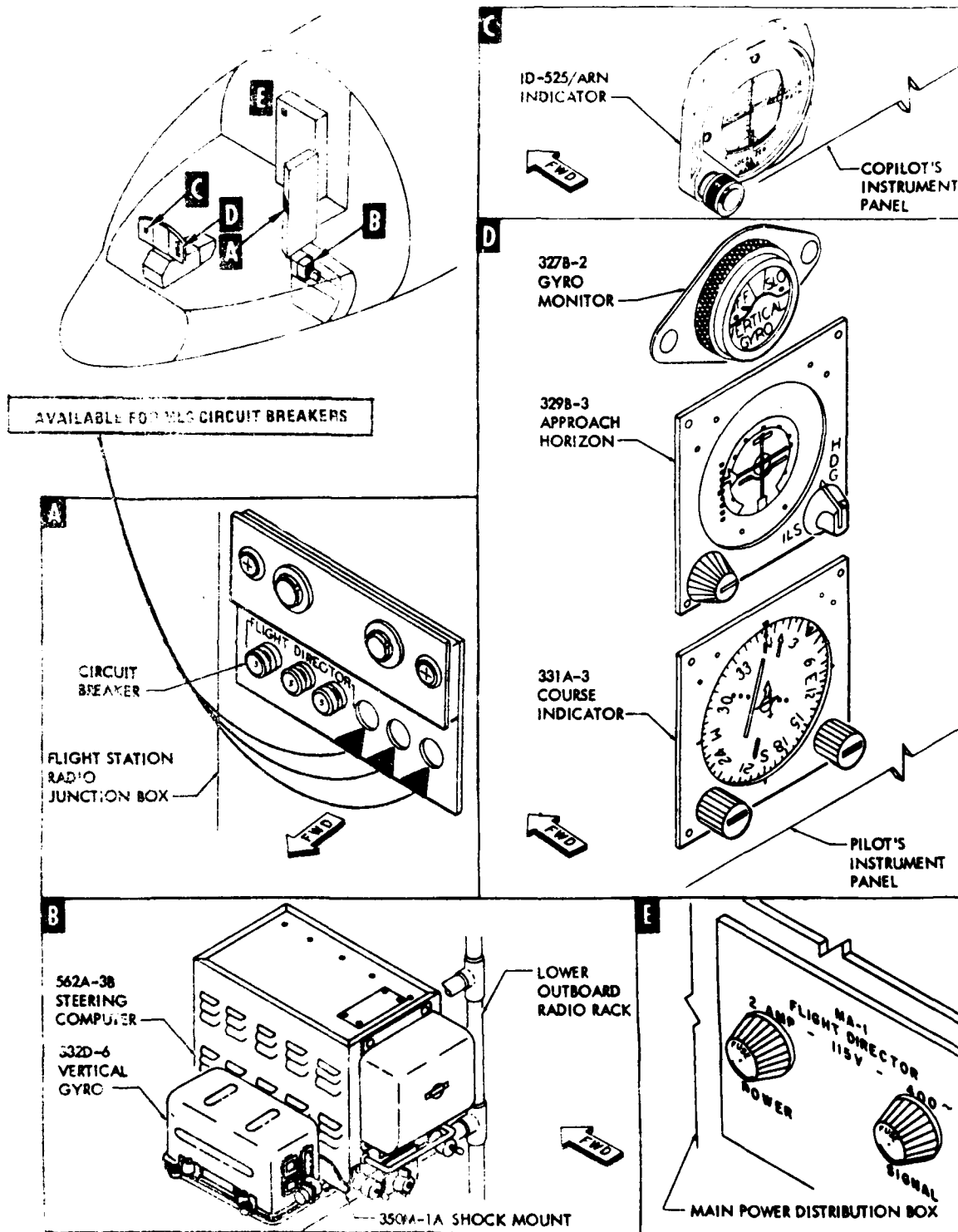


Figure 67 Flight Director Systems Components Locations

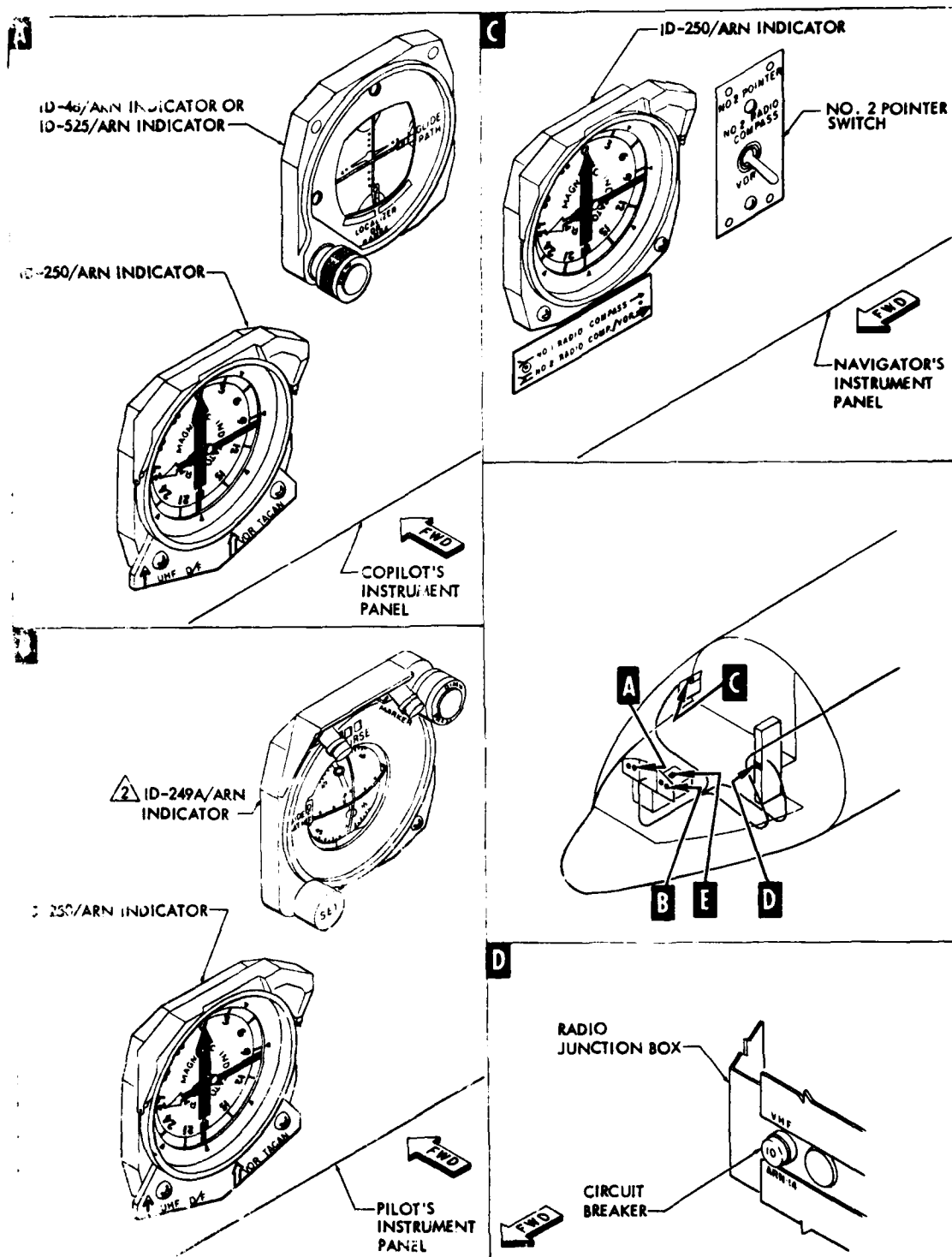
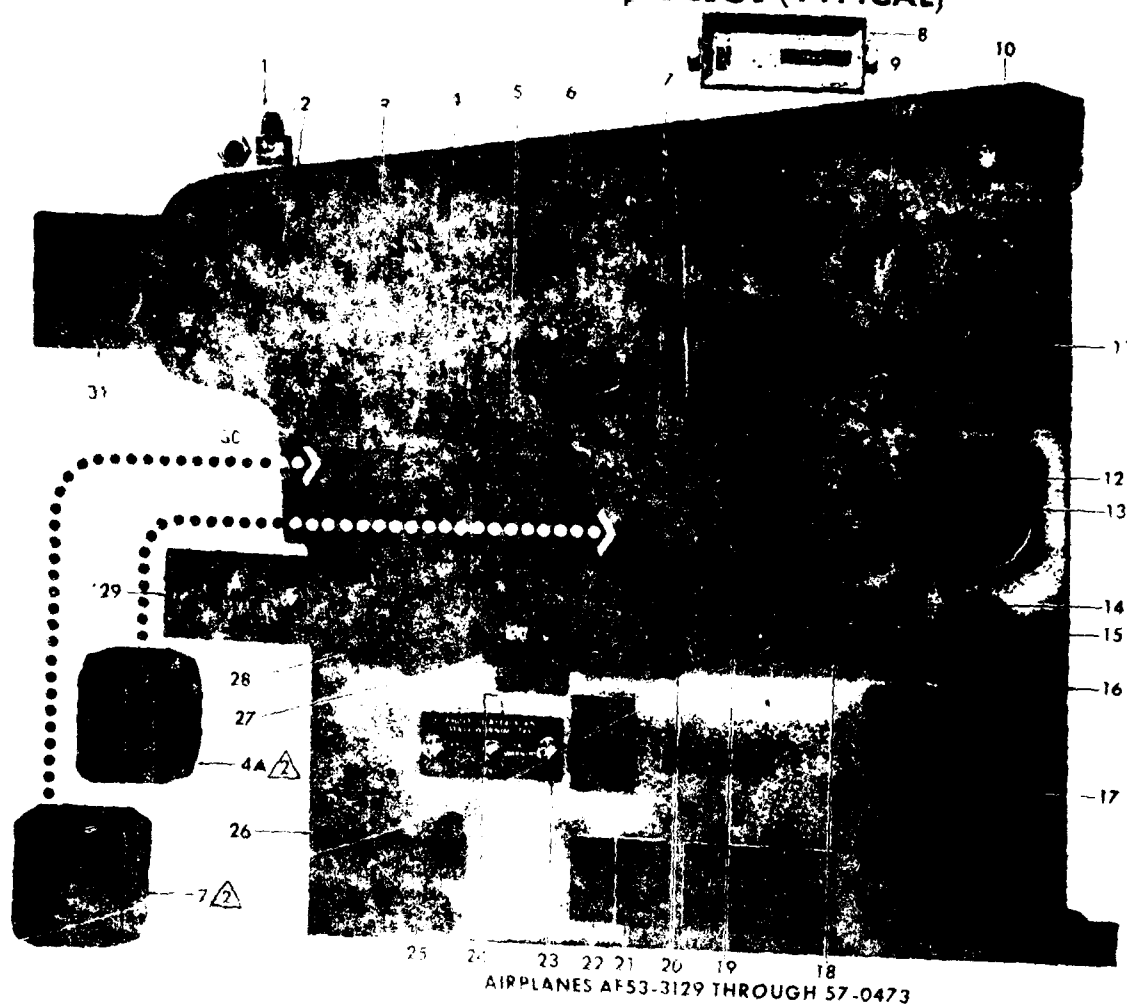




Figure 68 AN/ARN-14 VHF Navigation Receiver
Components Locations

[A] pilot's instrument panel (TYPICAL)

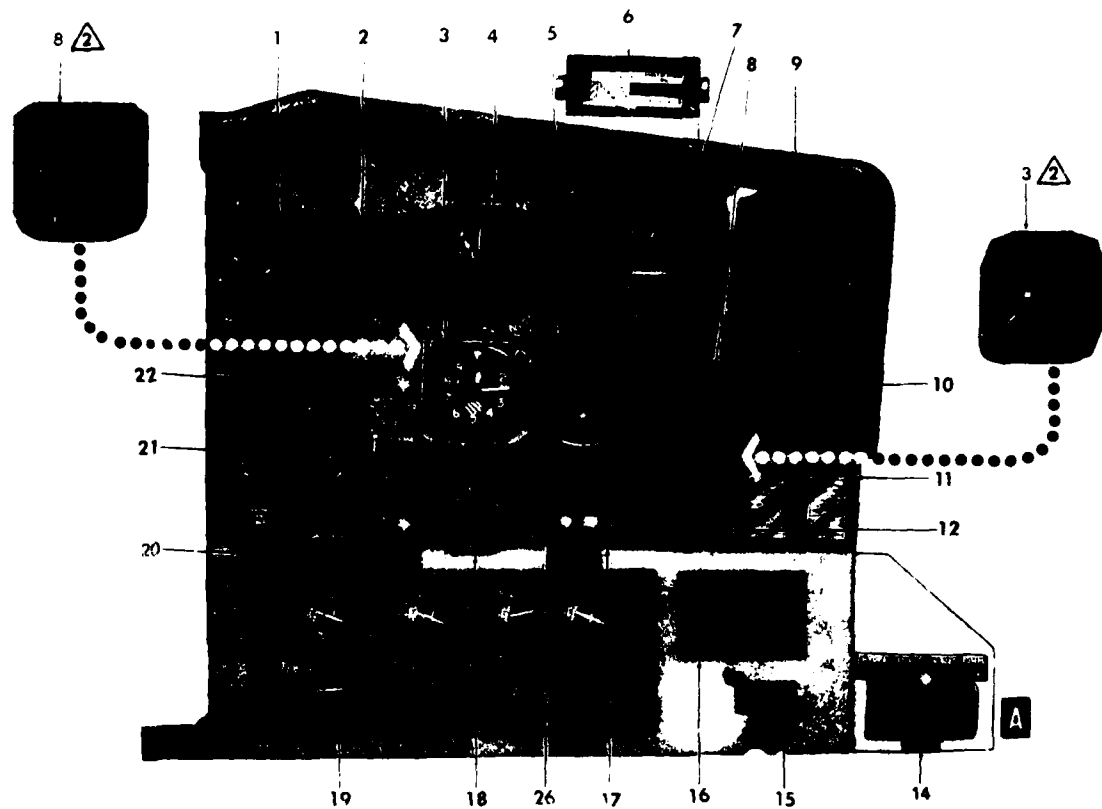


1. DOOR WARNING LIGHT
2. MAGNETIC COMPASS
3. AIRSPEED INDICATOR
4. ALTITUDE
- 4A. ALTITUDE ENCODER 
5. COURSE INDICATOR
6. N-1 COMPASS REPEATER INDICATOR
7. VERTICAL VELOCITY INDICATOR
8. ANGLE OF ATTACK INDICATOR 
9. ATTITUDE INDICATOR


10. MASTER FIRE WARNING LIGHT PANEL
11. RADAR ALTIMETER
12. RADIO MAGNETIC INDICATOR
13. TACAN RANGE INDICATOR
14. ELEVATOR TRIM TAB POSITION INDICATOR
15. WING FLAP POSITION INDICATOR
16. LOW OIL QUANTITY LIGHT
17. ENGINE AND PILOT'S INSTRUMENT LIGHT CONTROL PANEL
18. AIRPLANE TRIM TAB POSITION INDICATOR

Figure 69 Pilot's Instrument Panel (Typical)

[A] copilot's instrument panel typical



NOTE

 AIRPLANES MODIFIED
BY T.O. 1C-130-708.

 AIRPLANES MODIFIED
BY T.O. 1C-130-838.

PLANES AF53-3129 THROUGH 57-0473


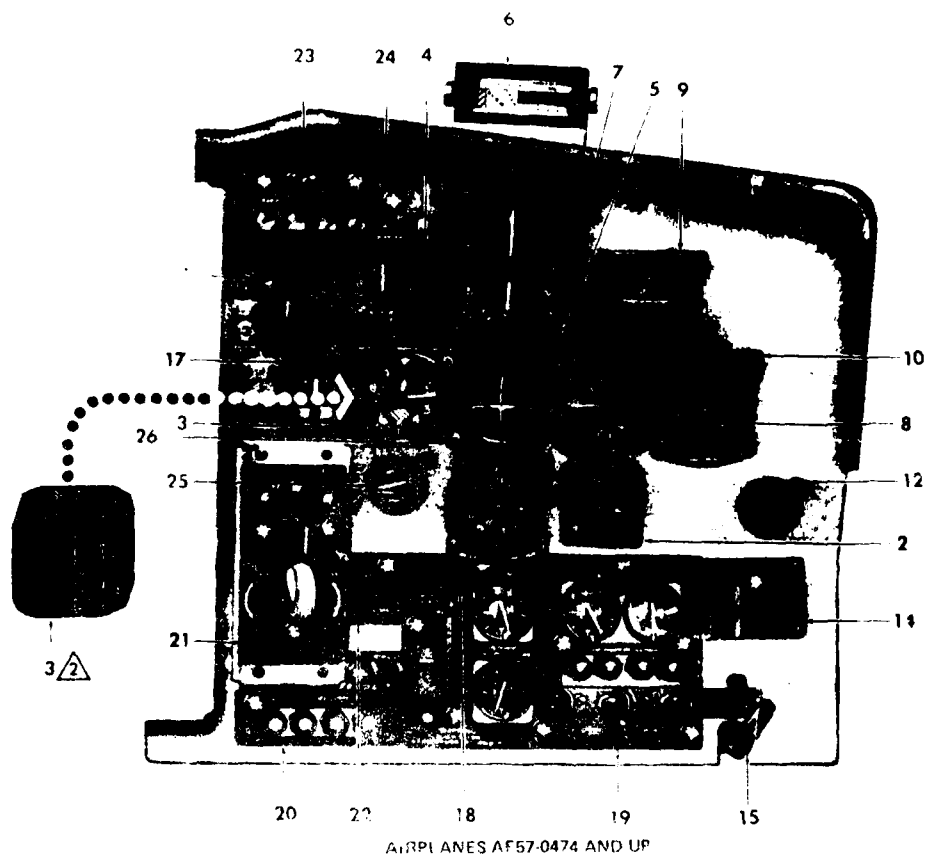
1. CABIN PRESSURE ALTITUDE INDICATOR
2. CLOCK
3. ALTITUDE
4. AIR SPEED INDICATOR
5. COURSE INDICATOR
6. ANGLE OF ATTACK INDICATOR 
7. HEADING INDICATOR
8. VERTICAL VELOCITY INDICATOR
9. ALTITUDE INDICATOR
10. RADIO MAGNETIC INDICATOR
11. ALTITUDE AND MAGNETIC COMPASS CORRECTION CARDS
12. FREE AIR TEMPERATURE INDICATOR
13. UTILITY PRIME SWITCH (AIRPLANES AF53-3129
THROUGH 56-0509)
14. HYDRAULIC SUCTION BOOST PUMP SWITCH PANEL
(AIRPLANES AF56-0510 AND UP)

Figure 70 Copilot's Instrument Panel (Typical)

A



15. AIR DIVERter HANDLE
 16. COPILOT'S INSTRUMENT LIGHT CONTROL
 17. TURN AND SLIP INDICATOR
 18. RADIO MAGNETIC INDICATOR
 19. HYDRAULIC CONTROL PANEL
 20. ELECTRONIC FUEL CORRECTION PANEL
 21. LANDING GEAR CONTROL PANEL
 22. MAIN LANDING GEAR DRIVE HI-TORQUE SWITCH PANEL
 (AIRPLANES AF55-023 AND UP)
 23. NACELLE OVERHEAT WARNING PANEL
 24. DOOR WARNING LIGHT
 25. WING FLAP POSITION INDICATOR
 26. MARKER BEACON LIGHT

Figure 7 Instrument Panel

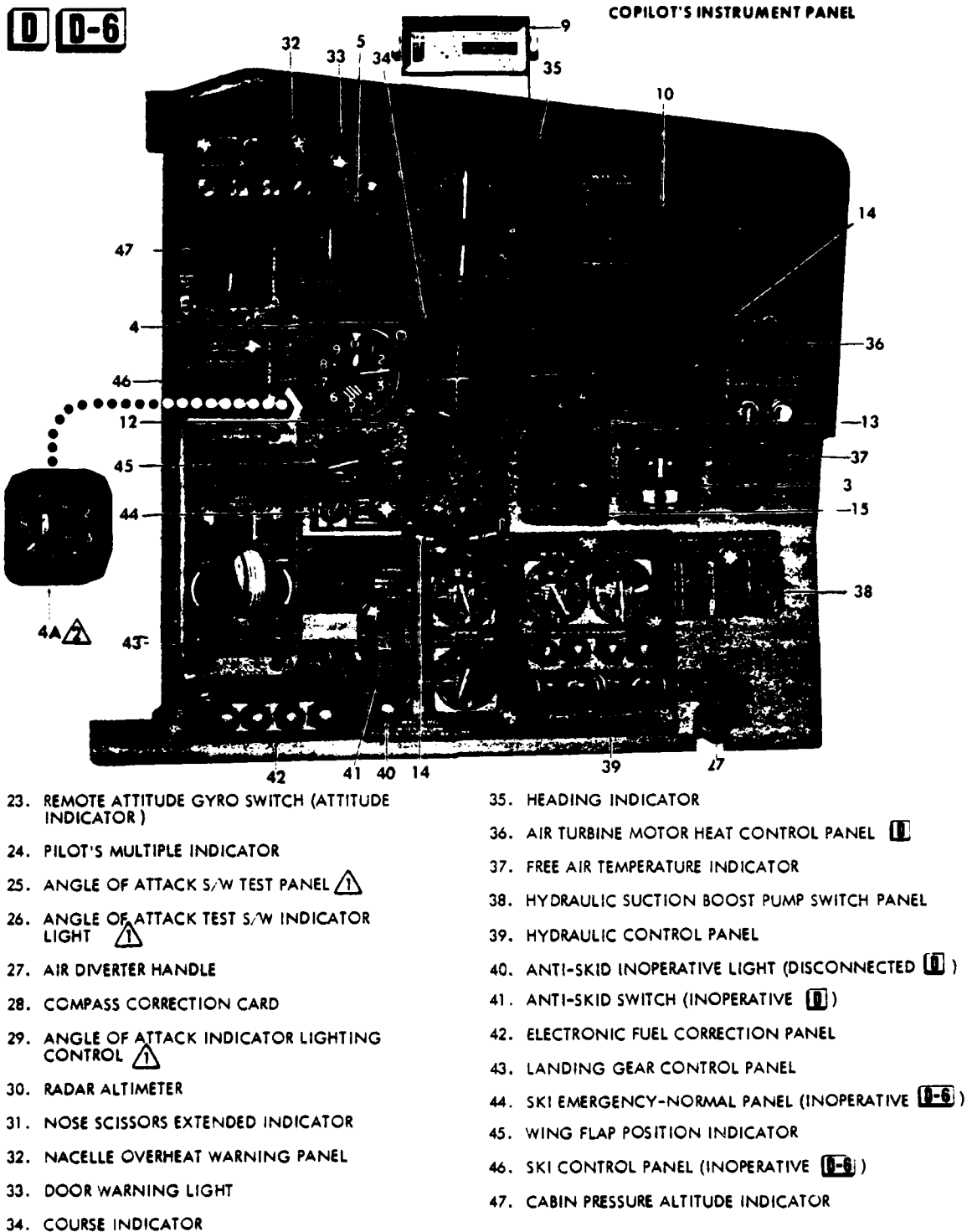


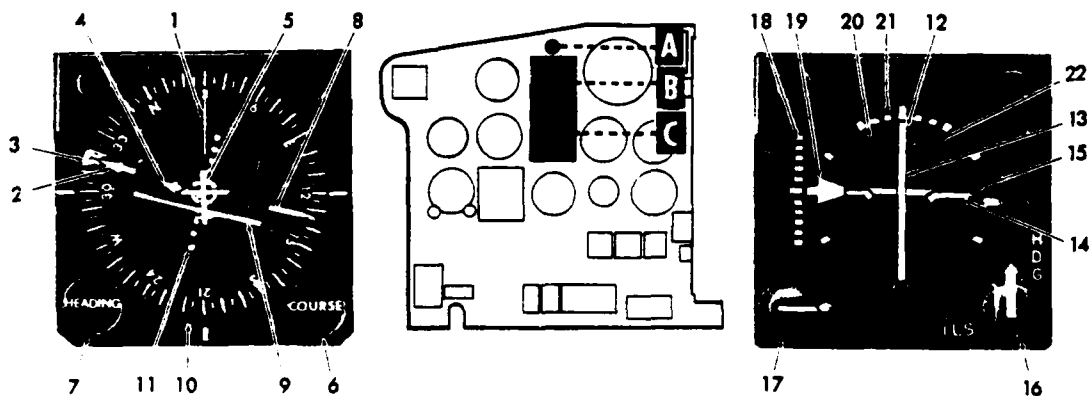
Figure 72 Copilot's Instrument Panel

flight director system indicators



C horizontal situation indicator

B attitude director indicator

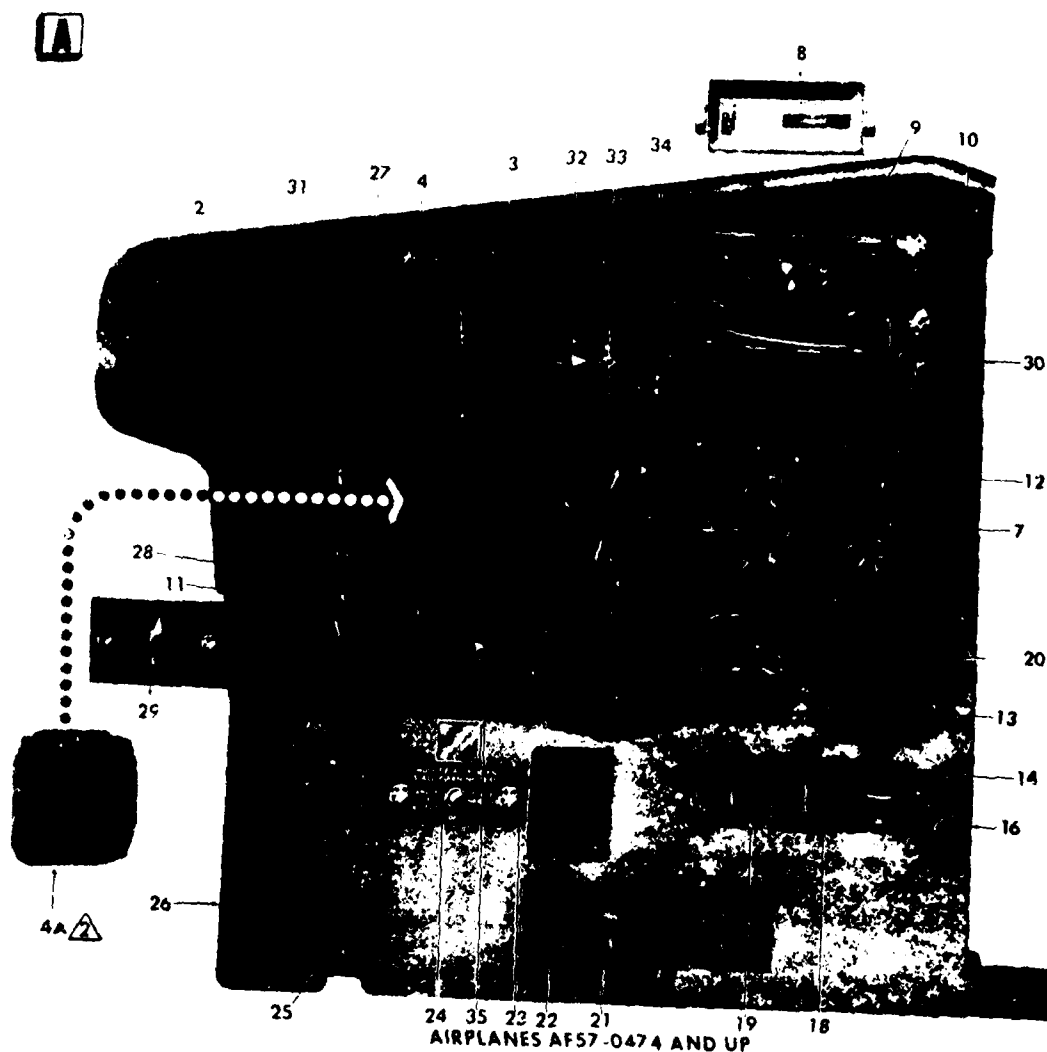


1. LUBBER LINE
2. COURSE ARROW (HEAD)
3. HEADING MARKER
4. TO - FROM INDICATOR
5. AIRCRAFT SYMBOL
6. COURSE SET KNOB
7. HEADING SET KNOB
8. COURSE ARROW (TAIL)
9. COURSE DEVIATION INDICATOR
10. COMPASS CARD
11. COURSE DEVIATION SCALE

12. BANK POINTER
13. BANK STEERING BAR
14. MINIATURE AIRCRAFT
15. HORIZON BAR
16. ILS-HDG SWITCH
17. PITCH TRIM KNOB
18. GLIDE SLOPE DEVIATION SCALE
19. GLIDE SLOPE INDICATOR
20. GLIDE SLOPE WARNING FLAG
21. BANK SCALE
22. COURSE WARNING FLAG

130A-1-33-120

Figure 73 Flight Director System Indicators



AIRPLANES AF57-0474 AND UP

- | | |
|--|--|
| 1. RUDDER TRIM TAB POSITION INDICATOR | 28. RADIO MAGNETIC INDICATOR |
| 20. CLOCK | 29. ANGLE OF ATTACK INDICATOR LIGHTING CONTROL ⚠ |
| 21. MARKER BEACON SWITCH | 30. MARKER BEACON LIGHT |
| 22. REMOTE ATTITUDE GYRO SWITCH (ATTITUDE INDICATOR) | 31. ACCELEROMETER |
| 23. ANGLE OF ATTACK S/W TEST PANEL ⚠ | 32. HORIZONTAL SITUATION INDICATOR |
| 24. ANGLE OF ATTACK TEST S/W INDICATOR LIGHT ⚠ | 33. FLIGHT DIRECTOR SYSTEM GYRO MONITOR |
| 25. AIR DIVERTER HANDLE | 34. ATTITUDE DIRECTOR INDICATOR |
| 26. COMPASS CORRECTION CARD | 35. PILOT'S MULTIPLE INDICATOR |
| 27. TURN AND SLIP INDICATOR | |

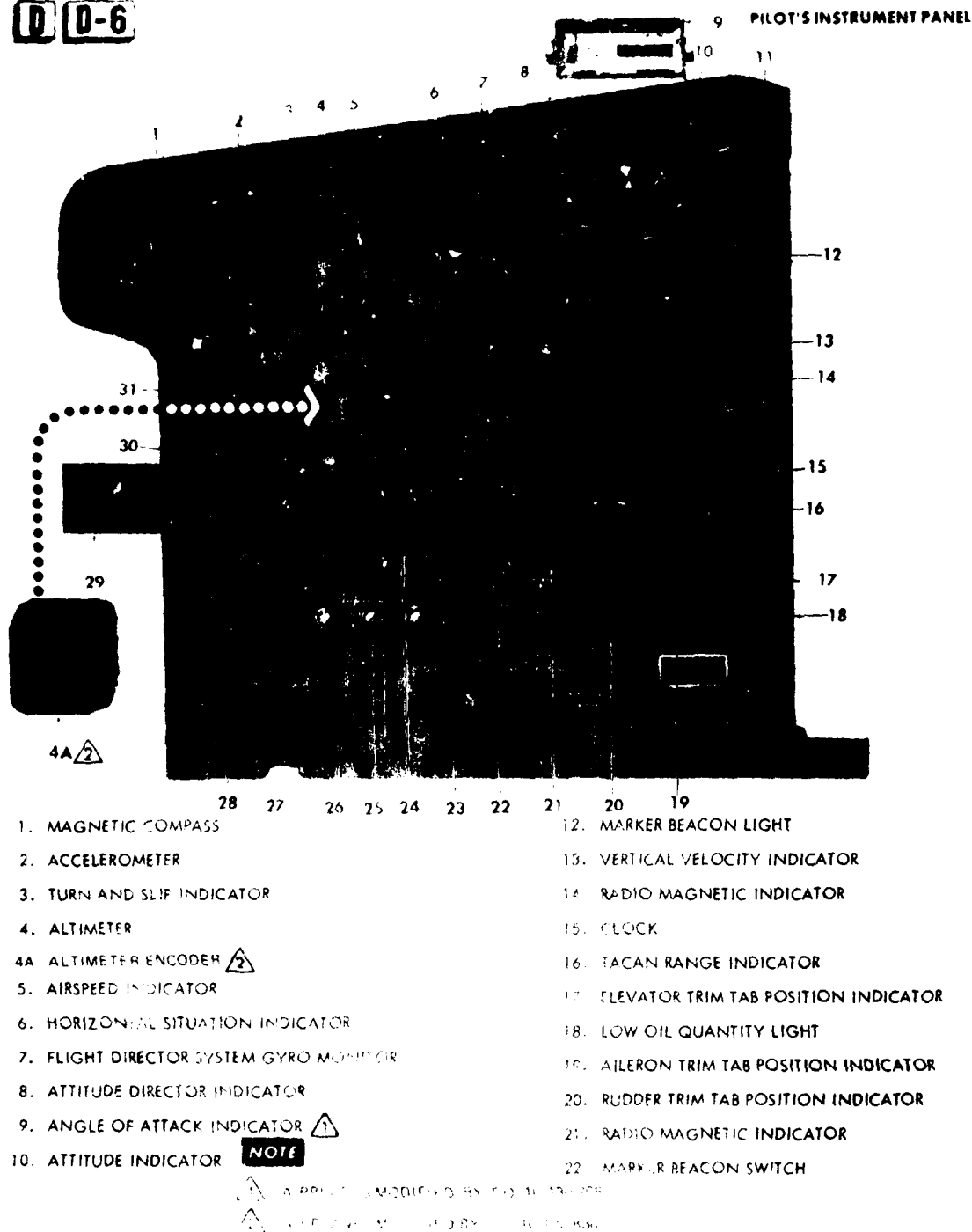
NOTE



- ⚠ AIRPLANES MODIFIED BY T.O. 1C 130-708.
 ⚠ AIRPLANES MODIFIED BY T.O. 1C 130-838.

Figure 4 Left Instrument Panel

pilot's and copilot's instrument panels

D D-6



- | | |
|--|--|
| 1. MAGNETIC COMPASS | 12. MARKER BEACON LIGHT |
| 2. ACCELEROMETER | 13. VERTICAL VELOCITY INDICATOR |
| 3. TURN AND SLIP INDICATOR | 14. RADIO MAGNETIC INDICATOR |
| 4. ALTIMETER | 15. CLOCK |
| 4A. ALTIMETER ENCODER  | 16. TACAN RANGE INDICATOR |
| 5. AIRSPEED INDICATOR | 17. ELEVATOR TRIM TAB POSITION INDICATOR |
| 6. HORIZONTAL SITUATION INDICATOR | 18. LOW OIL QUANTITY LIGHT |
| 7. FLIGHT DIRECTOR SYSTEM GYRO MONITOR | 19. AILERON TRIM TAB POSITION INDICATOR |
| 8. ATTITUDE DIRECTOR INDICATOR | 20. RUDDER TRIM TAB POSITION INDICATOR |
| 9. ANGLE OF ATTACK INDICATOR  | 21. RADIO MAGNETIC INDICATOR |
| 10. ATTITUDE INDICATOR NOTE | 22. MARKER BEACON SWITCH |



 A PIP MODIFIED BY T.O. 1C-130A-1
 A PIP MODIFIED BY T.O. 1C-130A-1

Figure 76 Pilot's and Copilot's Instrument Panels

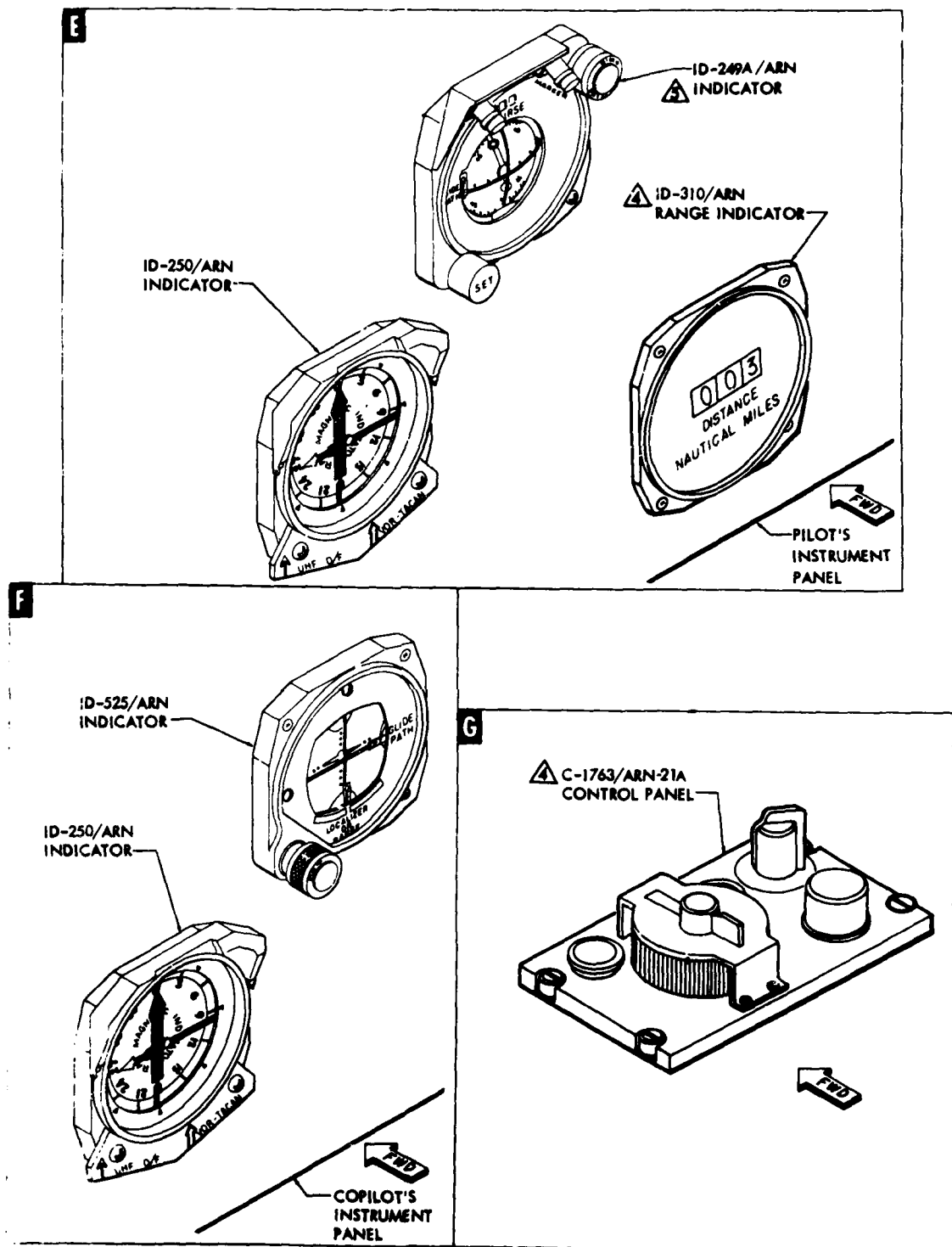


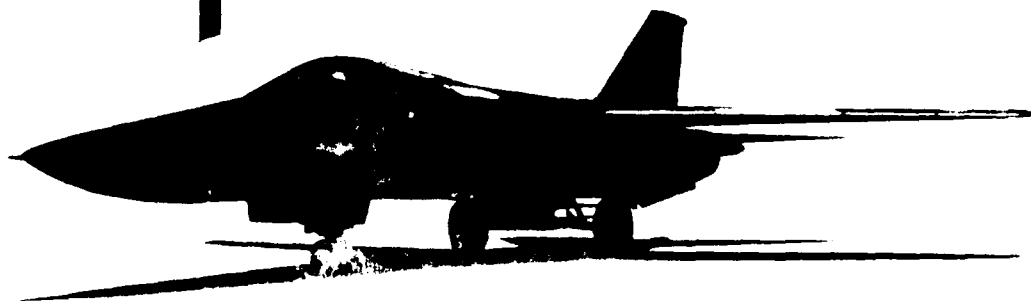
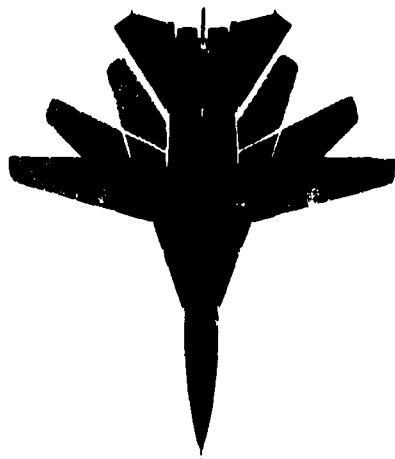
Figure 76 AN/ARN-21 TACAN System Components
Locations

T.O. 1F-111A-1

MLS CONSIDERATIONS



The F-111A/E



AE 300000 F09A-A

vii/viii

5.3 F-111A/E

5.3.1 General F-111A/E Information

The F-111A and F-111E are two place (side-by-side) long range fighter bombers built by General Dynamics, Fort Worth Division. The aircraft are designed for all-weather supersonic operation at both low and high altitude, utilizing a choice of missiles, guns, and bombs. An automatic low altitude terrain following system enhances penetration capability. Power is provided by two TF-30 axial-flow, dual-compressor turbo-fan engines equipped with afterburners. The wings, equipped with leading edge slats and trailing edge flaps, may be varied in sweep, area, camber, and aspect ratio, by the selection of any wing sweep angle between 16 and 72.5 degrees. This feature provides the aircraft with a highly versatile operating envelope. The empennage consists of a fixed vertical stabilizer with rudder for directional control, and a horizontal stabilizer that is moved symmetrically for pitch control and asymmetrically for roll control. Stability augmentation incorporates triple redundant features which enhance system reliability.

The F-111 A and F-111E aircraft equipment consists of a group of systems which, when functioning together, make up a complete aircraft weapons system. In many cases, the functions of one system depend upon inputs and loads from other systems. The aircraft systems are integrated so that maximum use of the information available within each system can be fully utilized with other aircraft systems.

The following systems were considered during the MLS interface analysis:

- Air Data
- Bomb-Navigation
- Flight Control
- Flight Director
- Flight Instruments
- Inertial Bombing-Navigation
- Instrument Landing
- Intercommunications
- Lead Computing Optical Sight
- Radar Homing and Warning
- TACAN
- Terrain Following Radar
- UHF Automatic Direction Finder

All of the systems aboard the aircraft employ analog elements for computation and interfacing. No digital computers are used. Of the systems considered, only the Flight Director, Instrument Landing, and Intercommunications systems are affected by the MLS installation.

The components of the above systems which are MLS related are as follows:

Flight Director System

Instrument System Coupler (ISC)
Navigation and Attack Panel
Flight Director Computer
Horizontal Situation Indicator (HSI)
Attitude Director Indicator (ADI)

Instrument Landing System (AN/ARN-58A)

Localizer Receiver, R-843/ARN-58
Glide Slope and Marker Beacon Receiver,
R844A/ARN-58

Since only single localizer and glide slope receivers are used, and only flight director approach coupling is available (no autopilot coupler), the approach avionics is Category I.

A block diagram of the existing navigation interface is illustrated in Figure 77. Only those elements involved with the MLS installation of possible MLS usage are included. As shown, the deviation and flag signals from the localizer and glide slope receiver, TACAN and Bomb-Navigation are applied to the Instrument System Coupler (ISC) which is mounted on the left main instrument panel. A mode select switch, integral to the ISC. (See Figure 78, lower left) is used to select the desired mode of operation.

When the ILS mode is selected, ISC logic routes the deviation and flag signals of the Localizer and glide slope receivers to the Flight Director Computer (FDC). This unit, in turn, processes the signals and applies lateral and vertical deviation, flag, and steering signals to the ISC logic. Appropriate switching in the ISC distributes these signals to the ADI, HSI and Lead Computing Optical Sight (LCOS, via lead and launch computer) displays.

When the ILS mode is selected, the position of the switch on the ISC is the only annunciation available during the entire approach. Loc arm and engage and glide slope arm and engage annunciations do not exist.

If the Airborne Instrument Low Approach (AILA) mode is selected, computed localizer and glide slope signals from the Bomb-Nav system (in conjunction with the Attack Radar System) are substituted for the ILS signals.

Referring to Figure 77, the HSI (pilot's side) and the BDHI (copilots side) both receive range and bearing signals from the TACAN system and these instruments can be time-shared by the MLS system.

Instrument landings can only be made by the crew member in the left seat. Only the left instrument panel includes navigation instruments (see Figure 79). With the exception of some basic instruments and a BDHI, the right main instrument panel (see Figure 80) is dedicated to controls and instruments associated with the weapons delivery capabilities of the aircraft system.

The ISC, HSI and ADI are illustrated on the left side of Figure 80) and are located on the left instrument panel. The ISC consists of an integral control panel and computer. Functional details of the HSI and ADI are illustrated on Figures 81 and 82, respectively.

A Lead Computing Optical Sight (LCOS, see Figure 83, is located on the left main instrument panel. This system functions as a heads up display and provides duplicate indications of the information presented on the ADI during operation of the ISC modes. Figure 84 illustrates a typical display presentation.

To integrate the recommended direct ILS replacement configuration (MLS-1) into the aircraft, the outputs of the localizer and glide slope receivers are interrupted (solid circles, Figure 77) and the MLS interface is interposed (see Figure 33, Typical Interface).

Very little space is available in the cockpit area (instrument panels, pedestal and right and left consoles) for new equipment (see Figure 85).

All of the instruments accept only analog interfaces.

5.3.2 F-111A/E MLS Recommendations

The MLS-1 configuration (CAT I) is the only system recommended for installation in the F111A/F111E type aircraft. This conclusion is based on the following:

1. Present low approach avionics is CAT I.
2. Only flight director coupled approaches are possible. Autopilot coupling is not available.
3. Only the left side of the cockpit includes low approach instruments.
4. Unused space in the cockpit area is very limited. Since a retrofit to a complex trajectory configuration (MLS-3, or MLS-4) would require additional controls and displays, an extensive redesign of existing control and display instrumentation to incorporate the new functions would be required.*
5. Present HSI course mechanism is not remotely slewable and both the MLS-3 and MLS-4 configurations require such a unit. It is possible to utilize a slewable bearing pointer as an alternate to course-slewing for MLS-3.
6. Accommodation of multiple MLS antennas may not be possible because of present antennas density.

Because F-111A/F-111E mission requirements do not appear to necessitate the need for DME during straight-in ILS type approaches, this added complexity and cost is not recommended.

*It should be noted that during preparation of this report discussions within the USAF were underway regarding an update of the F-111 Bomb Navigation system. If this results in a redesign of the existing Bomb-Nav Control Panel shown in Figure 86, the incorporation of a more flexible MLS configuration could result.

If the proposed bomb-nav system modification is adopted it may be possible to include additional changes which would provide an MLS-3 or MLS-4 configuration capability. The bomb-nav control panel (see Figure 86) must be modified to accomodate the selected capability. Changes to the Bomb-Nav system are beyond the scope of this report.

Installation of an MLS-1 system in the F111A/F111E type aircraft involves the addition of the following units:

<u>UNIT</u>	<u>QTY.</u>
MLS Angle Receiver	1
MLS Switching Unit	1
MLS-1 Tuner	1
MLS Angle Antenna	1

The first two units are remotely-located and these can be accomodated in various aircraft locations.

From the information available in the T.O.'s it is apparent that no open spaces are available in the cockpit area to accomodate an MLS-1 type tuner (see Figure 36). Existing panels will have to be redesigned and shifted. This task is beyond the scope of this study and cannot be accomplished without a physical inspection of various F111A/F111E aircraft.

MLS antennas must be mounted in the general area of the present localizer and glide slope antennas (see Figure 87). Due to the density of the various other antennas in this location, selection of an exact space for the MLS antennas is beyond the scope of this report.

On the present aircraft, both the left and right crew member have individual controls to switch on and adjust the volume of the localizer-identifying audio code. Space is not available on the existing panels (see Figure 78, lower right) to accomodate the MLS audio switches. These can be mounted on the left and right sidewalls (see Figures 88 and 89).

Figure 90 illustrates the present ILS receiver/ICS interface and the functions which must be interrupted and routed through the MLS switching unit are labelled (solid circles).

Figure 91 is an illustration of the present TACAN/HSI/BDHI interface. The wires associated with the range function are labelled and these must be routed through the MLS switching unit if the MLS DME is installed.

Empty holes exist on an essential bus panel to accomodate MLS circuit breakers. This panel is located on the aft console of the crew compartment. An illustration of this panel appears on the right in Figure 92.

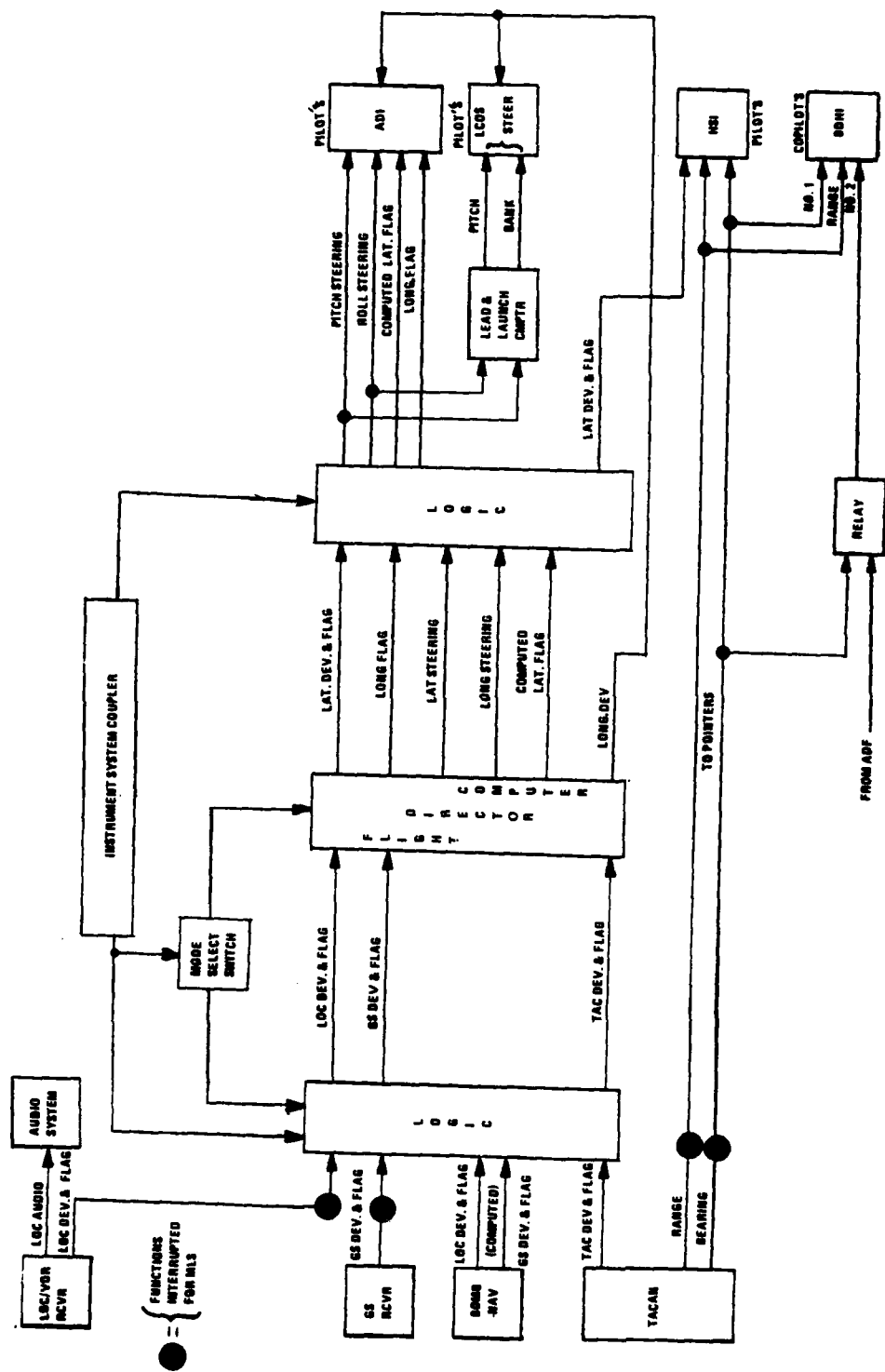
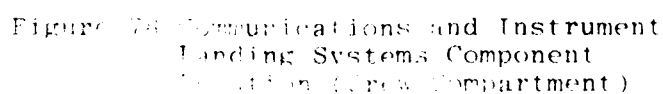
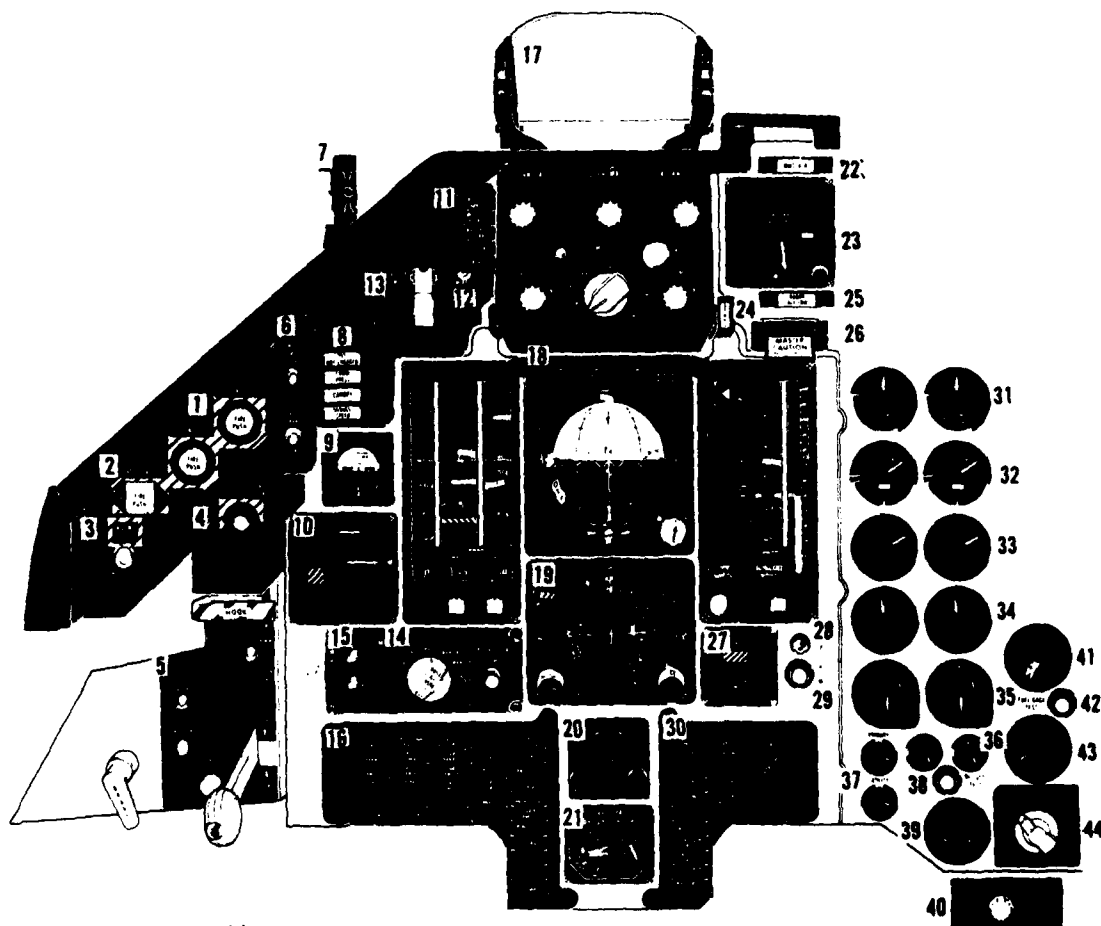


Figure 77 Block Diagram F-111A/E Navigation System



Left Main Instrument Panel (Typical)

1. Engine Fire Pushbutton Warning Lamps.
2. Fuselage Fire Pushbutton Warning Lamp.
3. Agent Discharge/Fire Detect Test Switch.
4. External Stores Jettison Button.
5. Landing Gear Control Panel (See fig. 1-18).
6. Pilot's ECM Pod Control Panel (See T.O. 1F-111A-1-2)
7. Angle-of-Attack Indexer.
8. Left Warning and Caution Panel.
9. Self Contained Attitude Indicator.
10. Wing Sweep Flap/Slat Position Indicator.
11. Upper Warning and Caution Panel.
12. Gun/Camera Control Switch.
13. Air/Air IR Missile Switch. (E) Rounds Counter. (A)
14. Instrument System Coupler Control Panel.
15. Landing Gear Position Indicator Lamps.

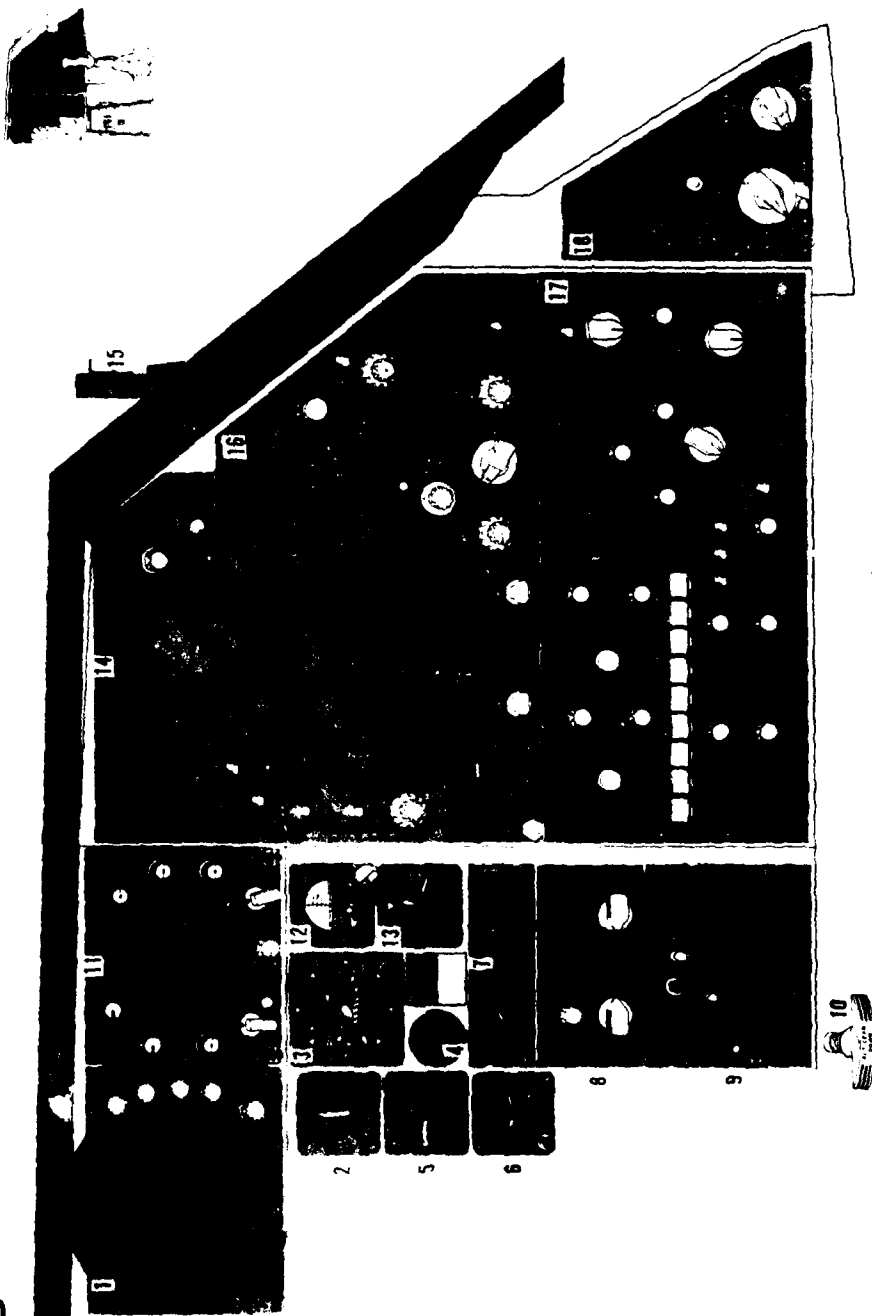
16. Left Main Caution Lamp Panel.
17. Lead Computing Optical Sight and Control Panel. (See fig. 1-89)
18. Upper Warning and Caution Lamp Panel.
19. Integrated Flight Instruments. (See fig. 1-35).
20. Dual Bombing Timer. (See fig. 1-70)
21. Control Surface Position Indicator.
22. Nose Wheel Steering/Air Refueling Indicator Lamp.
23. Radar Altimeter Indicator.
24. Stall Warning Lamp.
25. Radar Altitude Low Warning Lamp.
26. Master Caution Lamp.
27. Bomb Nav Distance-Time Indicator.
28. Takeoff Trim Indicator Lamp.
29. Takeoff Trim Button
30. Right Main Caution Lamp Panel.

31. Engine Tachometers.
32. Engine Turbine Inlet Temperature Indicators.
33. Engine Fuel Flow Indicators.
34. Engine Nozzle Position Indicators.
35. Engine Pressure Ratio Indicators.
36. Engine Oil Pressure Indicators.
37. Hydraulic Pressure Indicators.
38. Oil Quantity Indicator Test Button.
39. Oil Quantity Indicator.
40. Air Refueling Receptacle Lights Control Knob.
41. Fuselage Fuel Quantity Indicator.
42. Fuel Quantity Indicator Test Button.
43. Total/Select Fuel Quantity Indicator.
44. Fuel Quantity Indicator Selector Knob.

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Figure 79 Left Main Instrument Panel (Typical)

Right Main Instrument Panel (Typical)

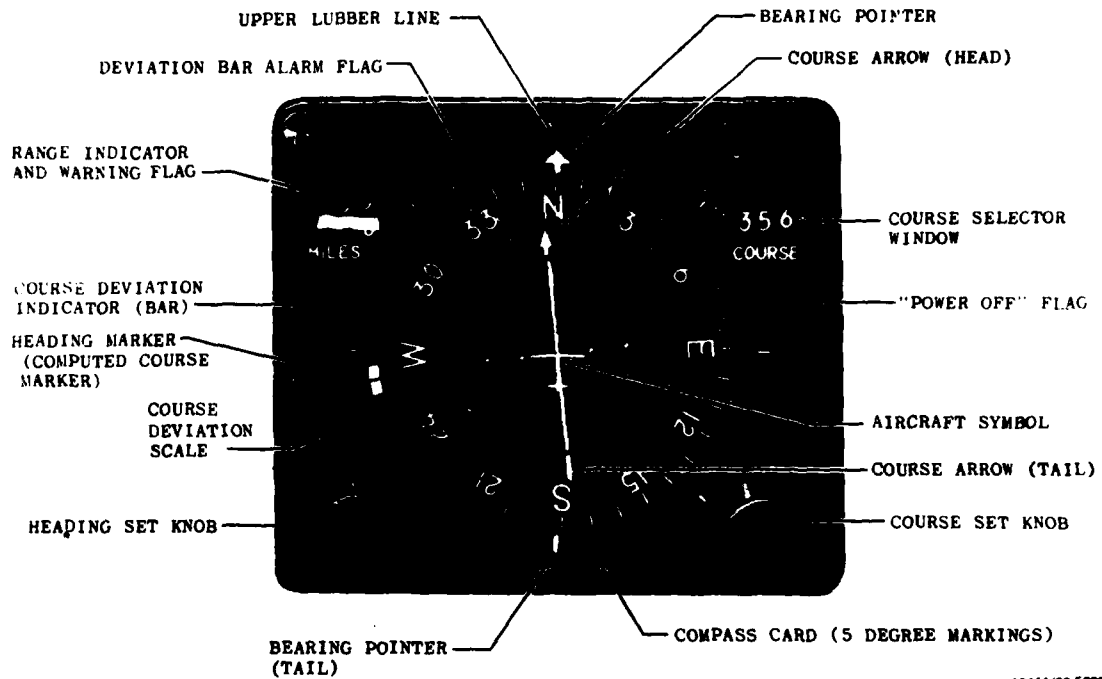


1. Terrain Following Radar Scope Panel. (See fig. 1-85)
2. Standby Airspeed Indicator.
3. Bearing-Distance-Heading Indicator.
4. True Airspeed Indicator.
5. Vertical Velocity Indicator.
6. Clock.
- * 7. SAM Sector Indicator/ECM Panel.

8. Offset Aimpoint Panel. (See fig. 1-65)
 9. UHF Radio Control Panel. (See fig. 1-54)
 10. Landing Gear Emergency Release Handle.
 - * 11. Radar Homing and Warning Scope Panel.
 12. Standby Altitude Indicator.
 13. Standby Altimeter.
- * Refer to T.O. 1F-111A-1-2

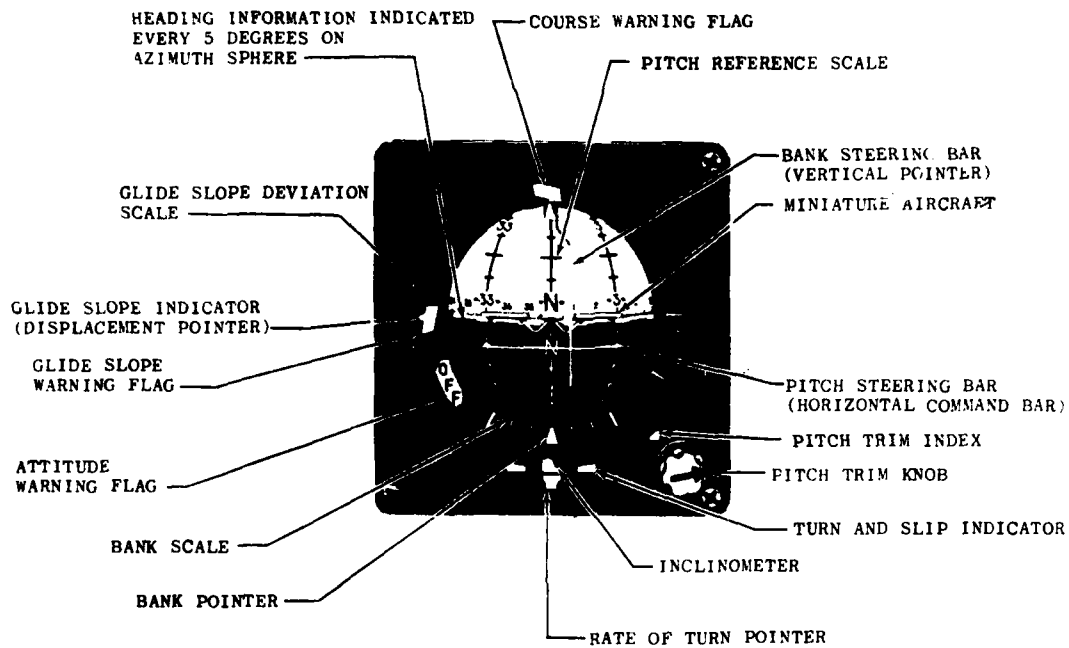
- * 14. Radar Homing and Warning Threat Panel.
15. Angle-of-Arrival Indexer.
16. Attack Radar Scope Panel. (See fig. 1-80)
17. Bomb Nav Control Panel. (See fig. 1-64)
18. Nuclear Weapons Control Panel. (See fig. 1-69)

Figure 80 Right Main Instrument Panel (Typical)



A5111J00-F0068

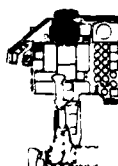
Figure 81 Horizontal Situation Indicator



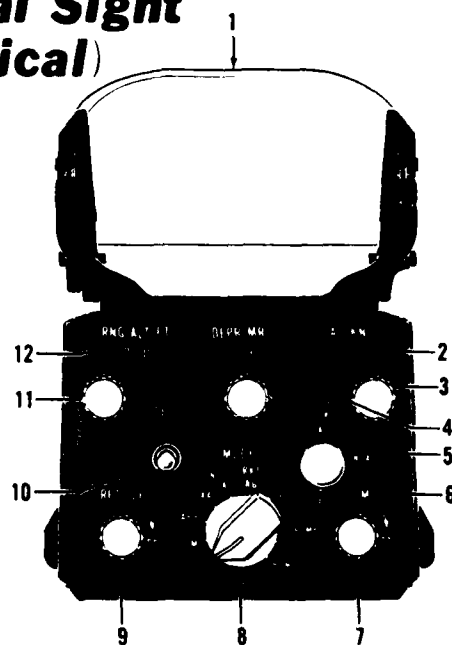
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Figure 82 Attitude Director Indicator

Lead Computing Optical Sight and Control Panel (Typical)



1. Optical Sight.
2. Preset True Airspeed Indicator.
3. True Airspeed Set Knob.
4. Reticle Depression Indicator.
5. Reticle Depression Set Knob.
6. Aiming Reticle Cage Lever.
7. Command Bar Brightness Knob.
8. Mode Select Knob.
9. Aiming Reticle Brightness Knob.
10. Test Switch.
11. Range / Altitude Set Knob.
12. Preset Range Indicator.



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Figure 83 Lead Computing Optical Sight
and Control Panel Typical

Aiming Reticle & Steering Bar Presentations

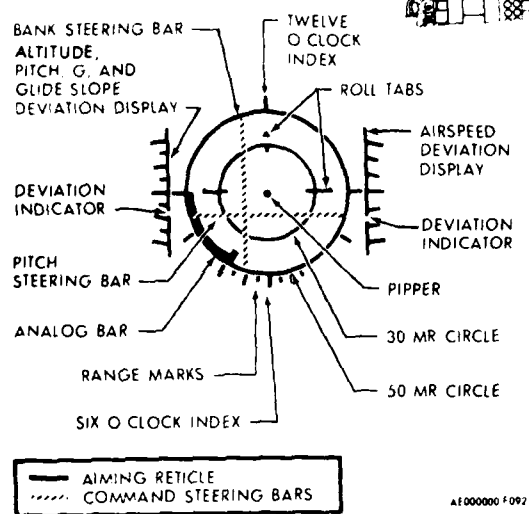
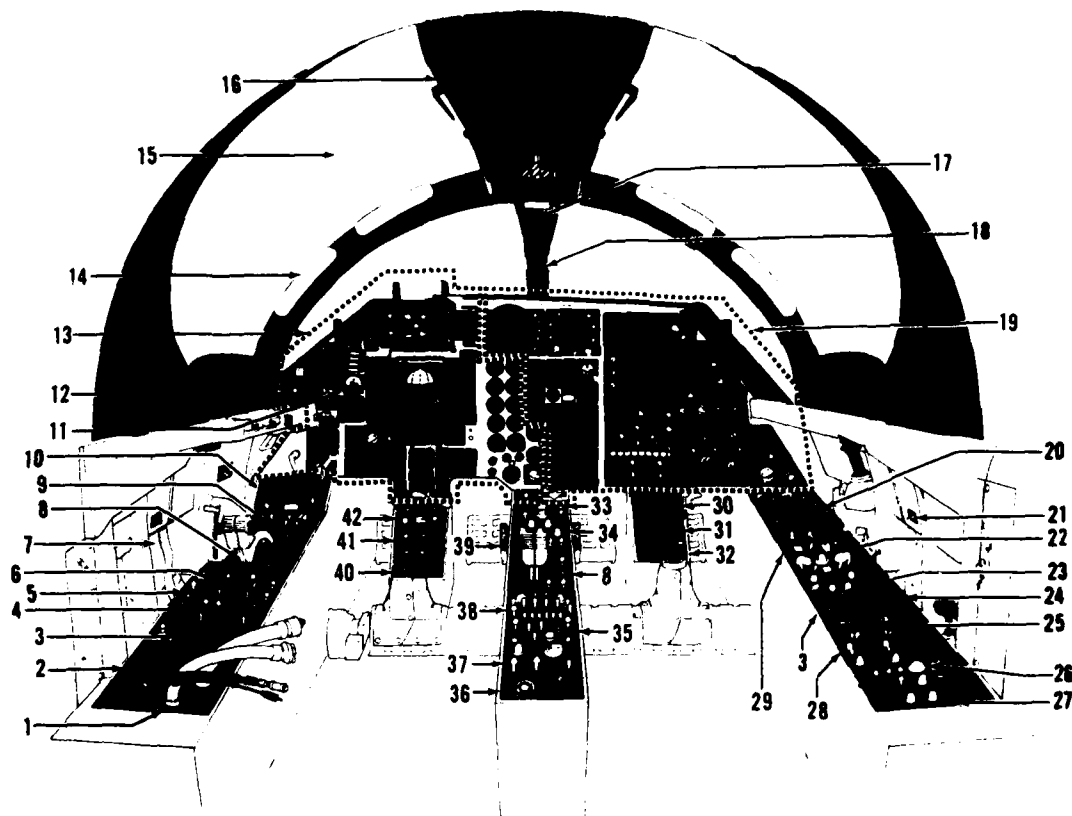


Figure 84 Aiming Reticle & Steering Bar Presentations

Crew Station General Arrangement (Typical)



* See T.O. 1F-111A-1-2

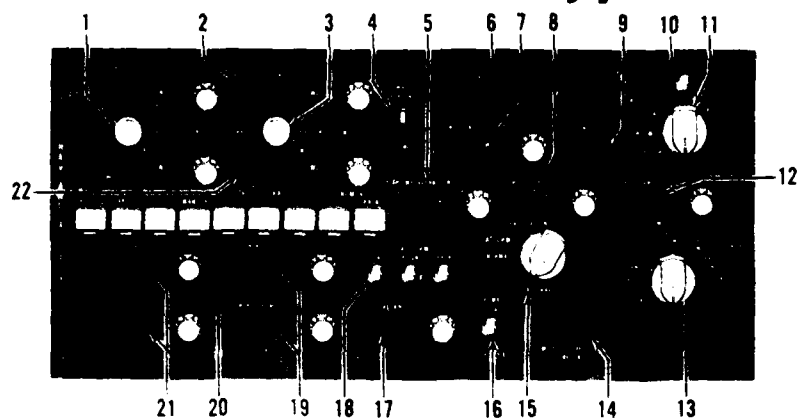
- | | |
|---|--|
| 1 Left Station Oxygen-Suit Control Panel (See fig. 1-48). | 21 Right Sidewall (See fig. 1-45). |
| 2 Oxygen Gage Panel (See fig. 1-49) (E) | 22 Attack Radar Control Panel (See fig. 1-78) |
| 3 Electrical Power Test Panel (See fig. 1-12) (A) | 23 HF Radio Control Panel (See figs. 1-55 or 1-56) |
| 4 Interphone Panel (2) (See fig. 1-58) | 24 Strike Camera Control Panel (See fig. 1-74). |
| 5 Auxiliary Flight Control Panel (See fig. 1-28) | * 25 ECM Control Panel. |
| 6 Flight Control Switch Panel (See fig. 1-29). | * 26 CMRS Control Panel. |
| 7 Autopilot Damper Panel (See fig. 1-30). | * 27 CMDS Control Panel. |
| 8 Left Sidewall (See fig. 1-21). | * 28 ECM Pod Control Panel. |
| 9 Throttle Panel (2) (See fig. 1-4) | * 29 ECM Destruct Control Panel. |
| 10 Miscellaneous Switch Panel (See fig. 1-61). | 30 Burst Control Panel (See fig. 1-66). |
| 11 Auxiliary Gage Panel (See fig. 1-17). | 31 TACAN Control Panel (See fig. 1-59) |
| 12 Self Contained Attitude Indicator | 32 ILS Control Panel (See fig. 1-60). |
| 13 Internal Canopy Latch Handles (2) | 33 Fuel Control Panel (See fig. 1-8) |
| 14 Left Main Instrument Panel (See fig. 1-5). | 34 TFR Control Panel (See fig. 1-84). |
| 15 Mirrors (4). | 35 Electrical Control Panel (See fig. 1-11). |
| 16 Canopy | 36 Scope Camera Control Panel (See fig. 1-76) |
| 17 Thermal Curtain (2). | 37 Air Conditioning Control Panel (See fig. 1-43). |
| 18 Canopy Center Beam Assembly. | 38 IFF Control Panel (See fig. 1-62) |
| 19 Magnetic Compass. | 39 Ejection Handles (2) |
| 20 Right Main Instrument Panel (See fig. 1-34). | 40 Antenna Select Panel (See fig. 1-63). |
| Weapons Control Panel (See fig. 1-71) (E) | 41 Windshield Wash/Anti-icing Control Panel (See fig. 1-46). |
| Armament Select Panel (See fig. 1-68) (A) | 42 Compass Control Panel (See fig. 1-33). |

Figure 85 Crew Station General Arrangement (Typical)

Section I
Description & Operation

I.O. 1F-111A-1

Bomb Nav Control Panel (Typical)



- | | | |
|--|---|---|
| 1. Present Position Hold Button. | 9. Ground Track and Groundspeed Counters (2). | 18. Platform Indicator Lamps (3). |
| 2. Present Position Counters (2). | 10. Go Lamp. | 19. Windspeed and Wind From Counters. |
| 3. Present Position Correction Button. | 11. Altitude/Test Selector Knob. | 20. Bomb Nav Fix Mode Selector Buttons. |
| 4. Magnetic Heading Synchronization Indicator. | 12. Trail/Range Counter. | 21. Offset Range and Offset Bearing Counters (2). |
| 5. Fixpoint Elevation Counter. | 13. Bomb Nav Mode Selector Knob. | 22. Destination Position Counters. |
| 6. True Heading Counter. | 14. Destination Distance/Time Counter. | |
| 7. Magnetic Variation Counter. | 15. Platform Alignment Control Knob. | |
| 8. Time-of-Fall Counter. | 16. Bomb Release Lamp. | |
| | 17. Glide/Dive Angle Counter. | |

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Figure 86 Bomb NAV Control Panel (Typical)

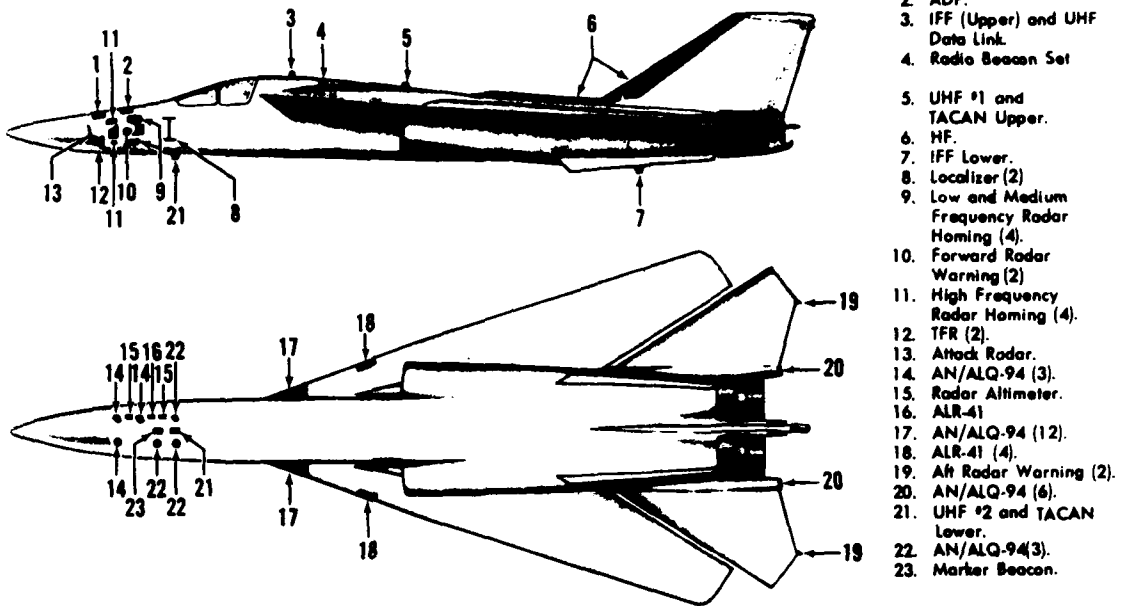
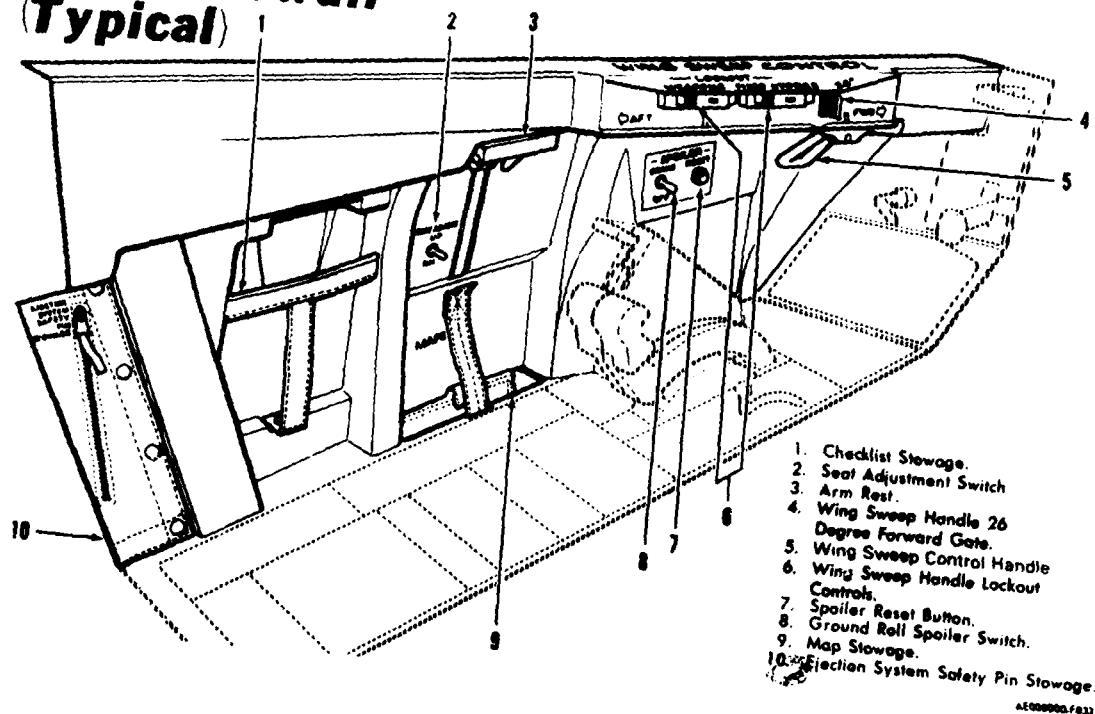
Antenna Locations (Typical)

Figure 87 Antenna Locations (Typical)

Left Sidewall (Typical)



1. Checklist Stowage.
2. Seat Adjustment Switch
3. Arm Rest.
4. Wing Sweep Handle 26 Degree Forward Gate.
5. Wing Sweep Control Handle
6. Wing Sweep Handle Lockout Controls.
7. Spoiler Reset Button.
8. Ground Roll Spoiler Switch.
9. Map Stowage.
10. Ejection System Safety Pin Stowage.

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Figure 88 Left Sidewall (Typical)

Right Sidewall (Typical)

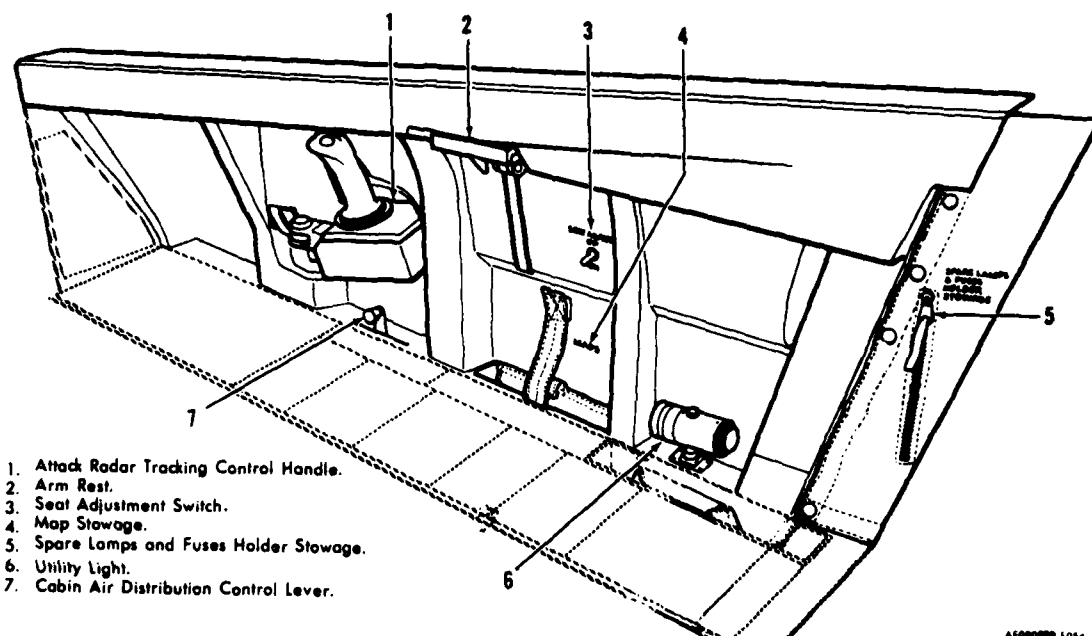
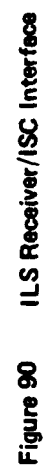
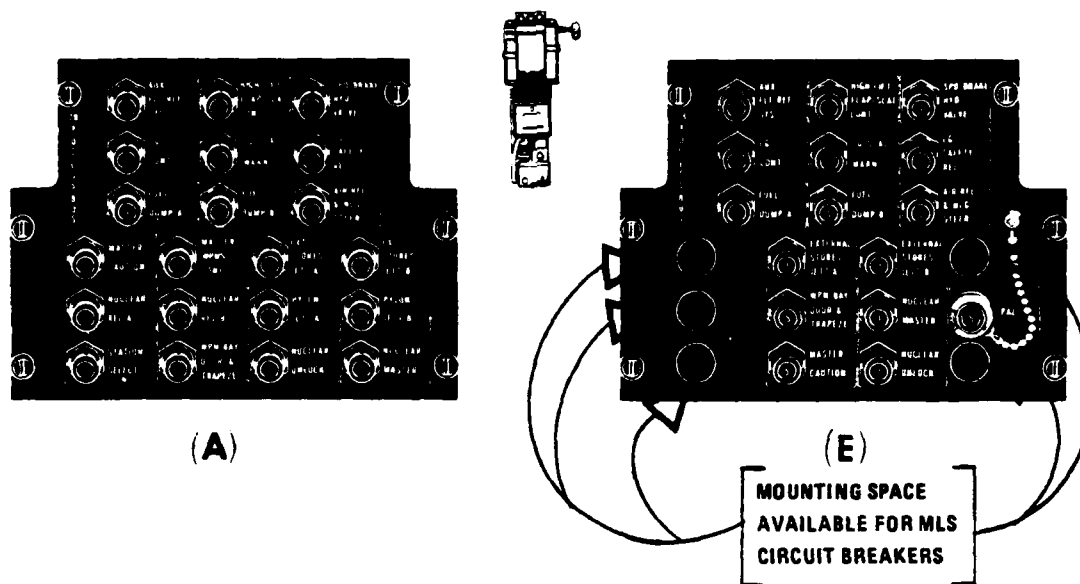


Figure 89 Right Sidewall (Typical)



Circuit Breaker Panel (Typical)



CIRCUIT BREAKER	FUNCTION
AFRS	Provides power to the primary att/hdg caution lamp, the aux/att caution lamp and used as the AFRS good signal.
HIGH LIFT FLAP/SLAT CONT	Provides power to the flap/slat asymmetry system and power to the flap/slat emergency motor.
SPEED BRAKE HYD VALVE	Provides power to the speed brake hydraulic valves.
LG CONT	Provides power to the extend and retract solenoids on the landing gear hydraulic valve.
LG/STALL WARN	Provides power to the landing gear handle warning lamp, gear down and lock indicator lamps, stall warning lamp, and to the warning tone generator.
LG SAFETY RELAY	Provides power to the ground safety switch circuit which inhibits certain aircraft functions.
FUEL DUMP A	Provides power to the fuel dump valve A and C.
FUEL DUMP B	Provides power to fuel dump valve B, dump relays A and B, and auto transfer solenoid valve.
AIR RFL & NLG STEER	Provides power to the air refueling receptacle or nose landing gear steering.
MASTER CAUTION	Provides power to the master caution lamp.

CIRCUIT BREAKER	FUNCTION
MASTER WPNS CONT (A)	Provides power to the master power switch on the armament select panel.
EXT STORES JET A	Provides power to external stores jettison button. (Has no effect on selective jettison.)
EXT STORES JET B	Same as Jett A. (Redundant)
NUCLEAR REL A (A)	Provides power for nuclear release.
NUCLEAR REL B (A)	Same as Rel A.
PYLON JETT A (A)	Provides power for normal jettison of the pylons.
PYLON JETT B (A)	Same as Pylon Jett A. (Redundant)
STATION SELECT (A)	Provides power to energize the station select relays.
WPN BAY DOOR & TRAPEZE	Provides power for operation of the weapon bay door and trapeze.
NUCLEAR UNLOCK	Provides power to monitor the status of the inflight lock on the MAU rack.
NUCLEAR MASTER	Provides source of power and control for the aircraft monitor and control system (AMAC).
PAL (E)	Provides power to PAL for enabling nuclear bombs for pre-arming.

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Figure 92 Circuit Breaker Panel (Typical)

MLS CONSIDERATIONS



5.4 A-7D

5.4.1 General A-7D Information

The A-7D is a single-engine, single-place, transonic, light attack aircraft, manufactured by Vought Corporation Systems Division, Dallas, Texas. Equipped with radar, navigational, communications, and weapon systems, the A-7D has an all-weather combat capability. The aircraft armament system includes a single, nose-mounted M61 gun, six wing-mounted store pylons, and two fuselage-mounted store pylons. A variety of missiles, bombs, and rockets can be carried and released in manual or automatic modes. A Navigation/Weapon Delivery System integrates many of the aircraft's avionic subsystems to provide for navigation to the target, computed run on target, computed weapon release, and return navigation. A Head-Up Display (HUD) System is provided to put all steering and attack displays between the pilot's eyes and the windshield. A single, large speed brake is mounted on the bottom side of the fuselage. An arresting hook retracts under the fuselage aft section. Stability, control augmentation, trim, and autopilot functions are provided by an Automatic Flight Control System.

The A-7D Aircraft avionics consists of a number of systems which, when functioning together, make up an integrated NAV/Weapon Delivery System (NWDS, see Figure 93). The subsystems of the NWDS are as follows:

- NAV WD Computer Set
- Inertial Measurement Set (IMS)
- Doppler Radar Set (DRS)
- Forward-Looking Radar System (FLR)
- Air Data Computer System (ADC)
- Head-Up Display Set (HUD)
- Armament Station Control Unit (ASCU)
- Projected Map Display Set (PMDS, not installed on all aircraft)

Peripheral equipment associated with the NWDS follows:

- Automatic Direction Finder (ADF)
- Radar Altimeter

Tacan Navigational Set

- * Instrument Landing System (ILS)
- * Flight Director Computer (FDC)
- * Altitude Director Indicator (ADI)
- * Horizontal Situation Indicator (HSI)
- * Mode Selection Switches and Relays

Intercommunication System

- * Elements of the Heading Mode System (HMS).

Signals from the NWDS, Tacan, ADF and Radar Altimeter are routed through the HMS.

All of the listed subsystems and peripheral equipment were considered during the MLS interface analysis. The tactical computer associated with the NAV WD computer set is a general purpose, stored-program, digital computer. It interfaces with the other subsystems via data links and analog elements. All interfacing with the peripheral equipment and the NWDS is analog.

Of the subsystems and peripheral equipment considered, only the flight director computer, relaying, and intercommunications are affected by the MLS installation.

Since only single elements are used for ILS and since approach coupling is available only via the flight director, the approach avionics is no better than Category I.

A block diagram of the existing heading (navigation) mode interface is illustrated in Figure 94. Only those elements involved with the MLS installation or possible MLS usage are included. As shown, signals from the various elements are applied to the flight director computer. This computer processes these signals and provides inputs to the left avionics relay assembly and to the pitch channel of the HUD system. Outputs of the relay assembly are, in turn, applied to the HSI, ADI and roll channel of the HUD system.

The ILS mode is activated by depressing the landing mode push-button switch (see Figures 95 a, b, and c, Ref. No. 4). As a result, localizer and glide deviation signals and flags are applied to the various instruments. In addition, the flight director computer provides flight path steering signals to the ADI and HUD for localizer and glide slope flight path control.

When the landing mode is selected, the cap of the pushbutton switch is illuminated and the legend "LDG" is annunciated. This is the only annunciation available during the entire approach.

Typical instrument panels are illustrated on Figures 96 and 97. The HSI and ADI are located in the center of the panel, and the HUD is located above the panel. Space is not available for MLS panels.

Functional details of the HSI and ADI are illustrated on Figures 98 and 99 respectively. The course pointer and readout on the existing HSI is not remotely slewable. Functional details of the HUD are illustrated on Figures 100a through 100e.

5.4.2 A-7D MLS Recommendations

Since the A-7D type aircraft must operate at forward air bases, where the benefits of MLS could be used to enhance mission effectiveness and aircraft survivability, an MLS-3 (Selectable Intercept of Final) or MLS-4 (Complex Trajectory) configuration capability is highly desirable. Due to weight and space restrictions on the aircraft, the lack of autopilot coupling for approach, and the fact that the MLS-3 configuration provides a significant reduction in pilot workload in comparison to the MLS-4 configuration, nothing more complicated than the MLS-3 configuration can be recommended. Moreover, further simulation and/or flight test work is required to prove out the merits of this level of complexity for a single-seat aircraft.

Installation of an MLS-3 system in the A-7D type aircraft involves the addition of the following units:

<u>ITEM</u>	<u>UNIT</u>	<u>QTY.</u>
1	MLS Angle Receiver	1
2	DME Interrogator	1
3	MLS NAV Coupler	1
4	MLS Switching Unit	1
5	MLS AZ/DME Display	1
6	MLS Tuner/Selector	1
7	MLS Angle Antenna	1

<u>ITEM</u>	<u>UNIT</u>	<u>QTY.</u>
8	MLS DME ANTENNA	1
9	Audio Panel (Switches)	1

Items 1 through 4 are remotely located in the avionics bay. If available space is critical, the following are alternate solutions to conserve space and reduce weight:

1. Replace existing flight director computer with custom MLS NAV Coupler which is unique for the A-7D aircraft. An adapter may eliminate the need for disturbing the existing wiring.
2. Absorb the NAV Coupler functions into the present tactical digital computer. This involves a significant program change as a minimum but more importantly, it requires a major investigation effort to determine feasibility.
3. If neither of these alternate solutions is feasible, then only an MLS-1 (direct ILS replacement) configuration is applicable to the A-7D type aircraft.

The AZ/DME display can be mounted above and to the right of the HSI on the instrument panel (see Figures 96 and 97). If this is not physically possible, the DME readout can be eliminated and an azimuth readout can be mounted in this location. If this DME readout is eliminated, the DME information on the HSI can be changed from distance-to-transition to raw MLS DME.

Space is available on the lower portion of the righthand console in the cockpit to mount the MLS Tuner/Selector and the MLS Audio panel (see Figures 100 and 102). Space is not available on the lefthand console (see Figures 103 and 104).

MLS antennas must be mounted in the general area of the present g. deslope antenna (see Figure 105). An exact location is beyond the scope of this report; however, no complications are expected.

Figure 106 illustrates the present audio controls. Space is not available to accommodate the two MLS audio switches. As previously noted, these will be mounted on the right lower console (see Figures 101 and 102).

Figures 107 and 108 illustrate the present localizer and glide-slope receiver interface and the functions which must be interrupted and routed through the MLS switching unit.

Figure 109 illustrates the present TACAN/HSI interface and the functions which must be interrupted in order to display MLS range, bearing (pointer No. 1) and intercept course (pointer No. 2). Utilizing pointer No. 2 for the intercept course is not the optimum solution; however, it precludes the need for replacing the HSI with one with a remotely slewable course function. The range and bearing functions must be routed through the MLS switching unit. The HSI requires an analog interface for these functions and the MLS NAV Coupler provides the desired converted outputs.

DC power is available for MLS units and space is available on the circuit breaker panel in the avionics compartment to accommodate the MLS circuit breakers (see Figure 110).

[illegible]

235

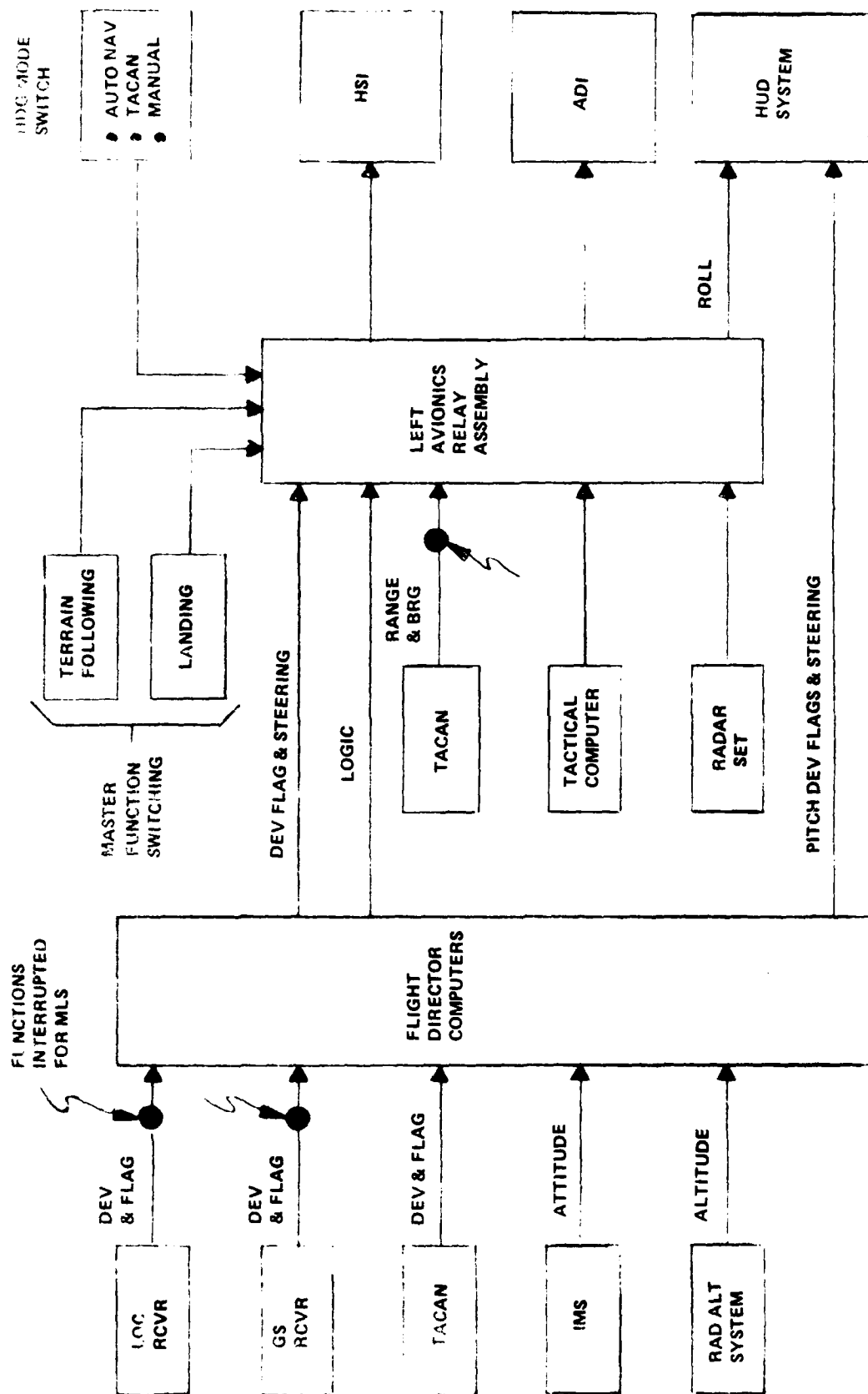


Figure 94 Heading (Navigation) Mode Block Diagram

ILS CONTROLS

AIRCRAFT → [16] [18] → [26]

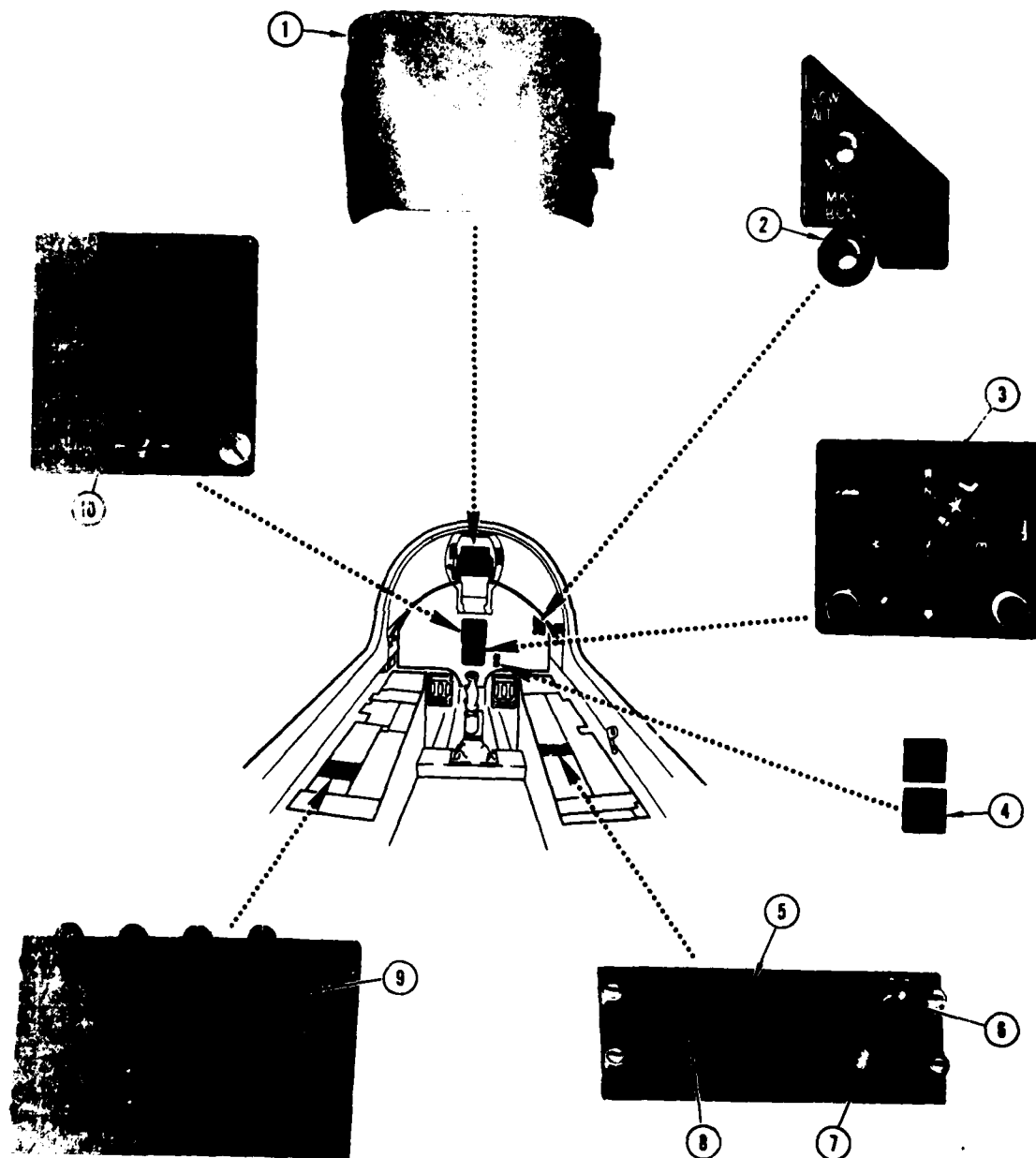


Figure 95a ILS Controls

ILS CONTROLS

AIRCRAFT [17] [27] →

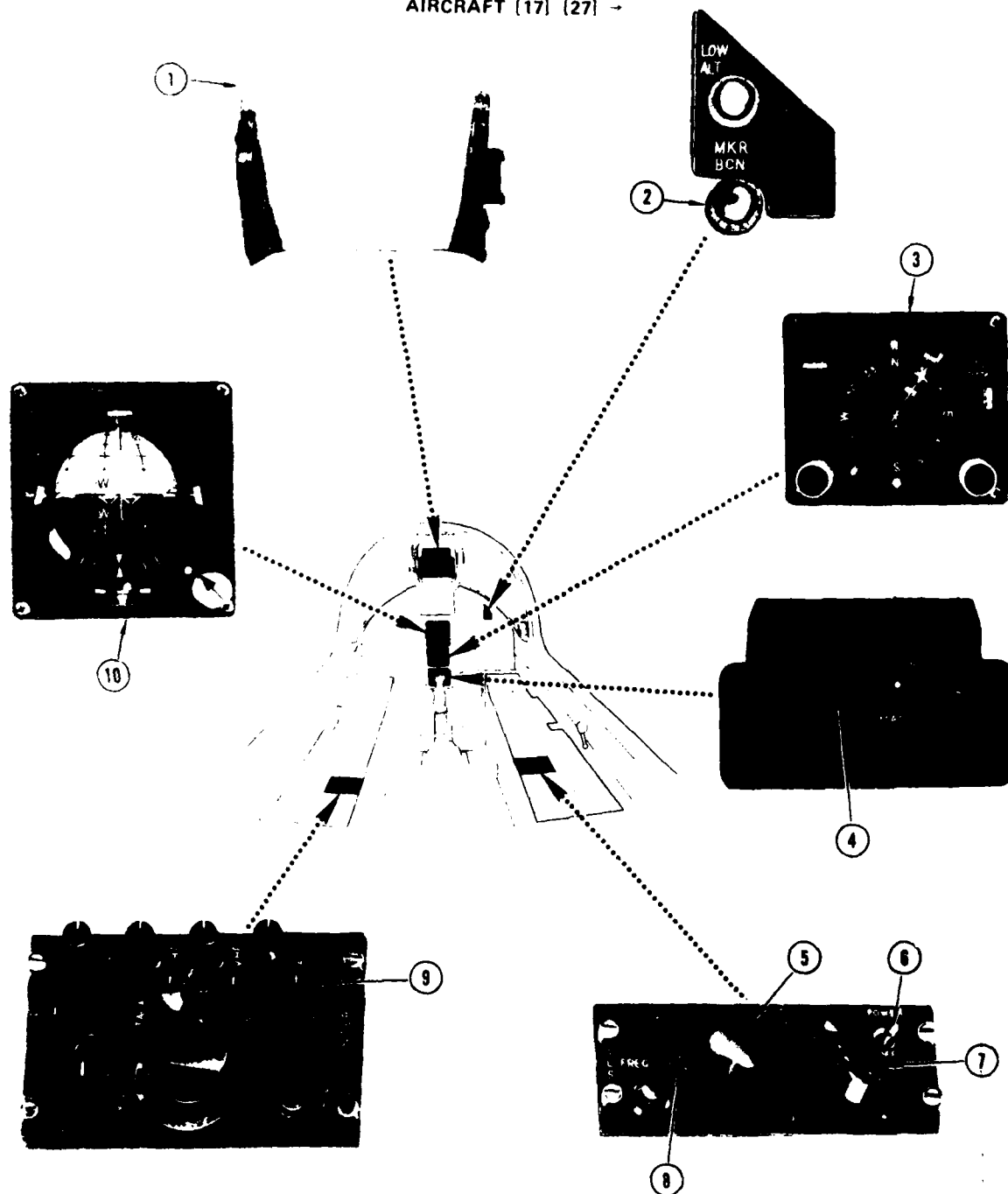


Figure 95b

ILS CONTROLS

Component	Function
1. Head-up display	Displays ILS landing symbols and angle-of-attack bracket when LDG mode master function switch is depressed. Indications include raw ILS deviation (landing flight path lines) and flight director computer steering commands (flight director symbol).
2. MKR BCN light	On — indicates passage over a 75.0 megacycle marker beacon.
3. Horizontal situation indicator	Course deviation bar indicates amount and direction of deviation from localizer beam during landing (raw localizer deviation). Course deviation bar flag appears if localizer signal is not adequate for reliable display.
4. LDG mode master function switch	Pressed — energizes landing mode circuitry in Flight Director Computer, heading mode relay, and HUD to enable displays for detection and capture of ILS localizer and glide slope beam.
5. Frequency selector	Used to select the desired localizer and paired glide slope frequencies.
6. POWER switch	POWER — applies operating power to localizer and glide slope receivers. OFF — disconnects power to receivers.
7. VOL control	Rotated clockwise increases localizer audio level.
8. FREQ indicator	Indicates selected localizer frequency.
9. Intercommunication panel ILS monitor	Pulled — enables ILS audio to be heard in pilot's headset. Turned to adjust volume.
10. Attitude director indicator	Pressing the LDG mode master function switch permits ILS information to be displayed on the ADI. The Flight Director Computer issues steering commands to the ADI vertical and horizontal pointers and to the HUD landing symbols. Raw glide slope deviation is indicated on the ADI glide slope indicator. Horizontal pointer alarm flag and vertical pointer alarm flag stowed out of view as long as glide slope and localizer signals are reliable and Flight Director Computer operation is normal.

Figure 95c

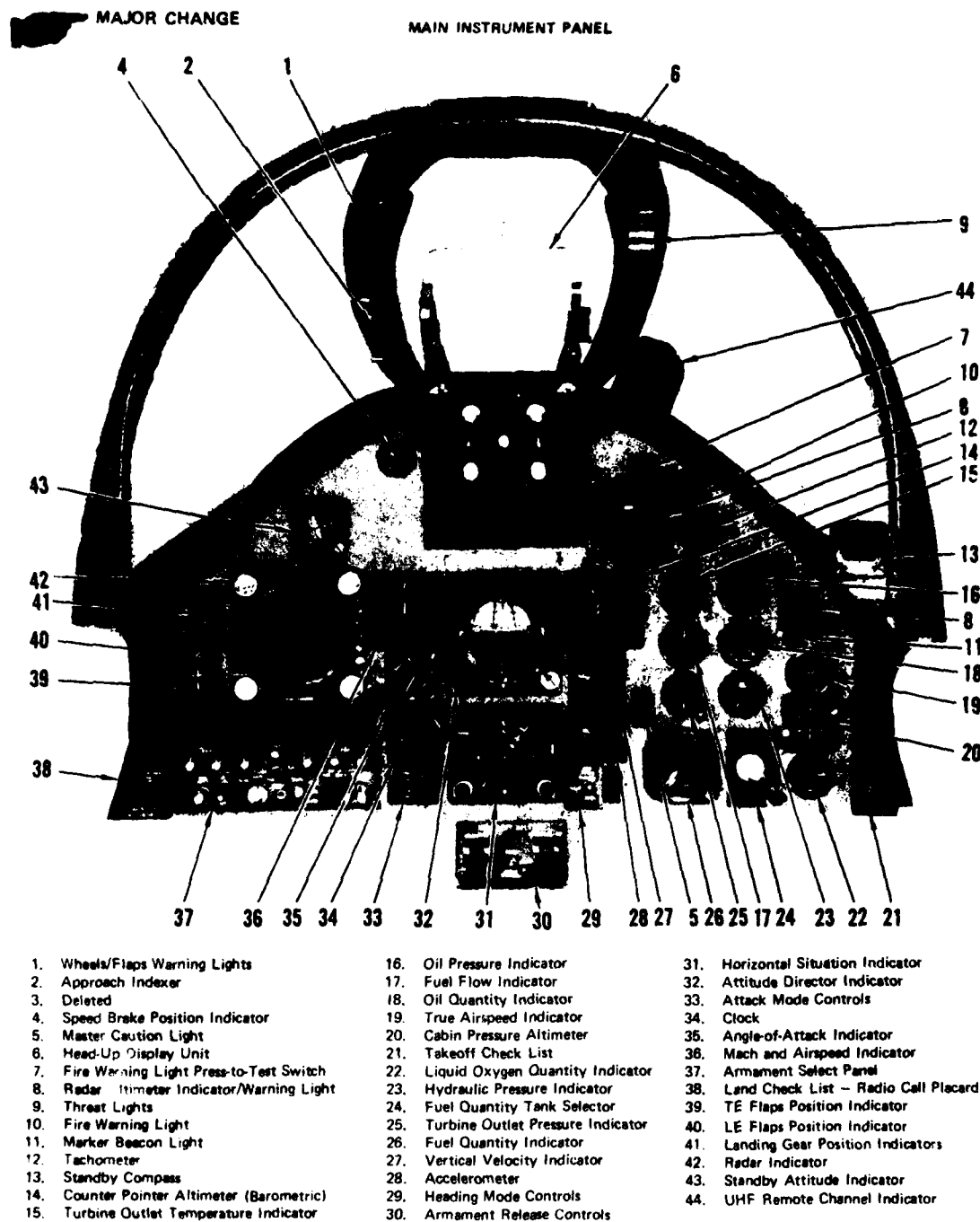
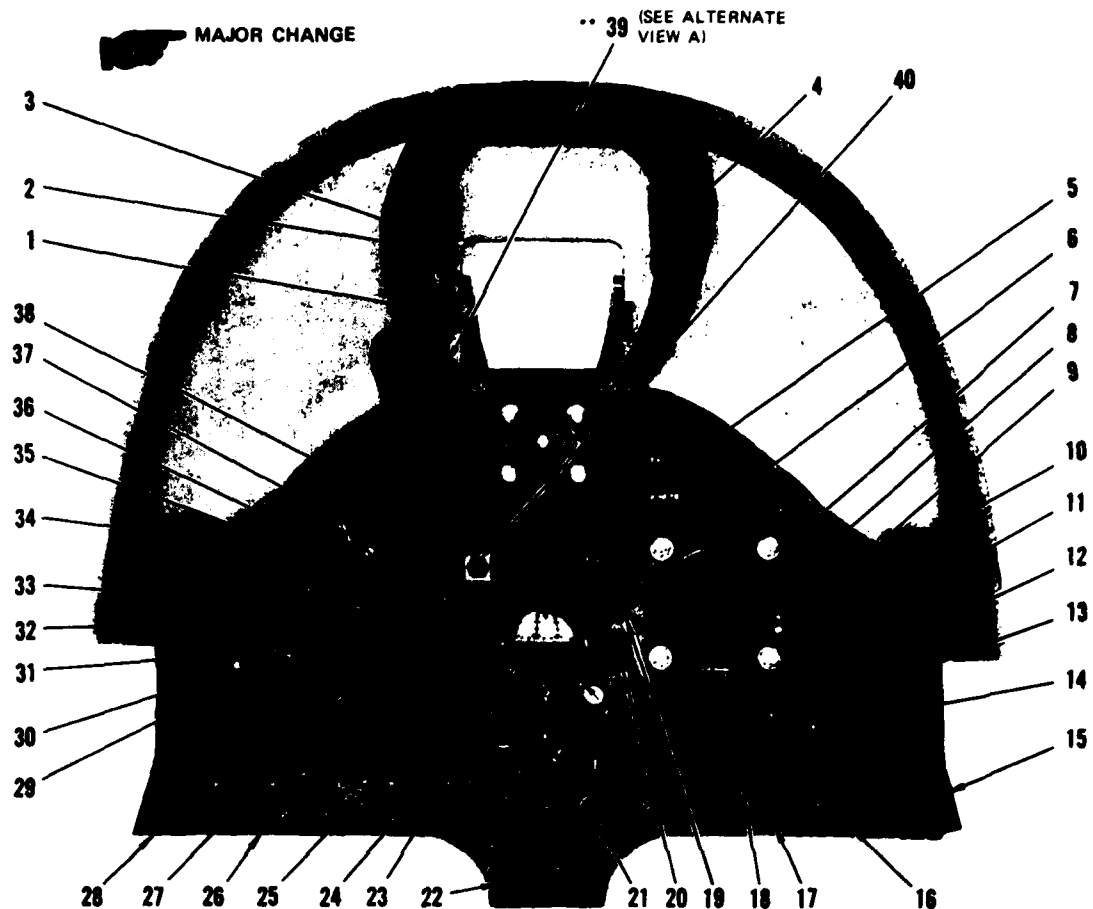
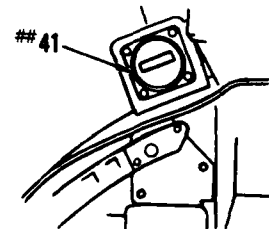


Figure 96 Main Instrument Panel



- | | |
|--|---|
| 1. Approach indexer | 21. Horizontal situation indicator |
| 2. IFR and wheel/flaps warning lights | 22. Heading mode controls |
| 3. Head-up display unit | 23. Attitude director indicator |
| 4. Threat lights | 24. Clock |
| 5. Radar set control | 25. Counter pointer altimeter |
| 6. Oil quantity indicator | 26. Armament select panel |
| 7. Radar altimeter warning light | 27. Angle-of-attack indicator |
| 8. Marker beacon light | 28. Land checklist — radio call placard |
| 9. Fuel flow indicator | 29. Armament release controls |
| 10. Accelerometer | 30. Vertical velocity indicator |
| 11. Turbine outlet temperature indicator | 31. Attack mode controls |
| 12. Oil pressure indicator | 32. Speed brake indicator |
| 13. Tachometer | 33. Radar altimeter indicator |
| 14. Turbine outlet pressure indicator | 34. Standby compass |
| 15. Takeoff checklist | 35. Threat lights and correlate switch |
| 16. Fuel quantity indicator | 36. Mach and airspeed indicator |
| 17. Projected map display | 37. Standby attitude indicator |
| 18. Radar indicator | 38. ECM threat display unit |
| 19. Fire warning light | **39. UHF remote channel indicator |
| 20. Master caution light | 40. Standby gyro erect switch |
| | ##41. UHF remote channel indicator |



ALTERNATE VIEW A

**Airplanes before T.O. 1A-7D-785
 ##Airplanes after T.O. 1A-7D-785

Figure 97 Alternate View A

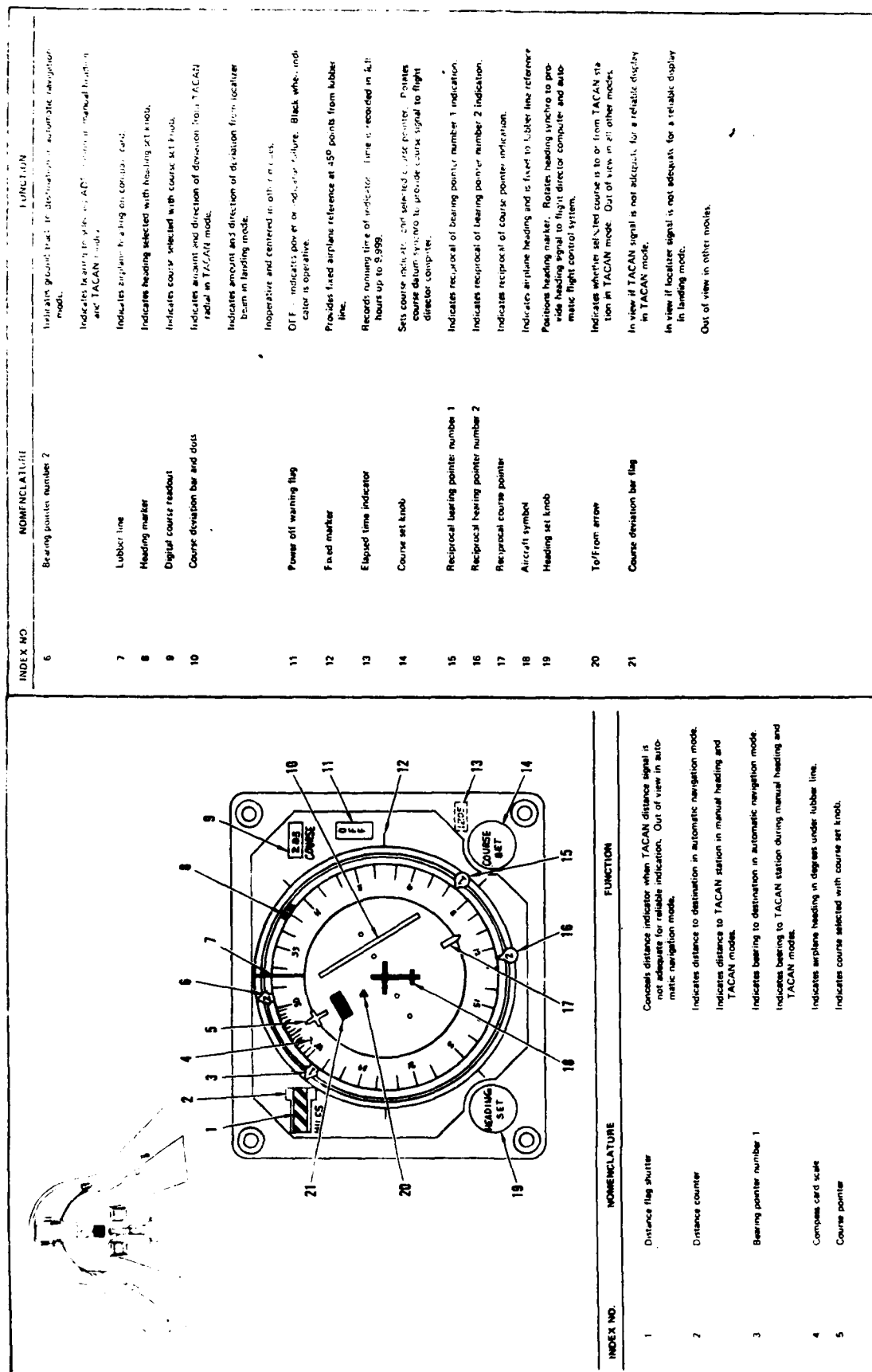


Figure 98 Heading Mode System Horizontal Situation Indicator Controls And Indicators

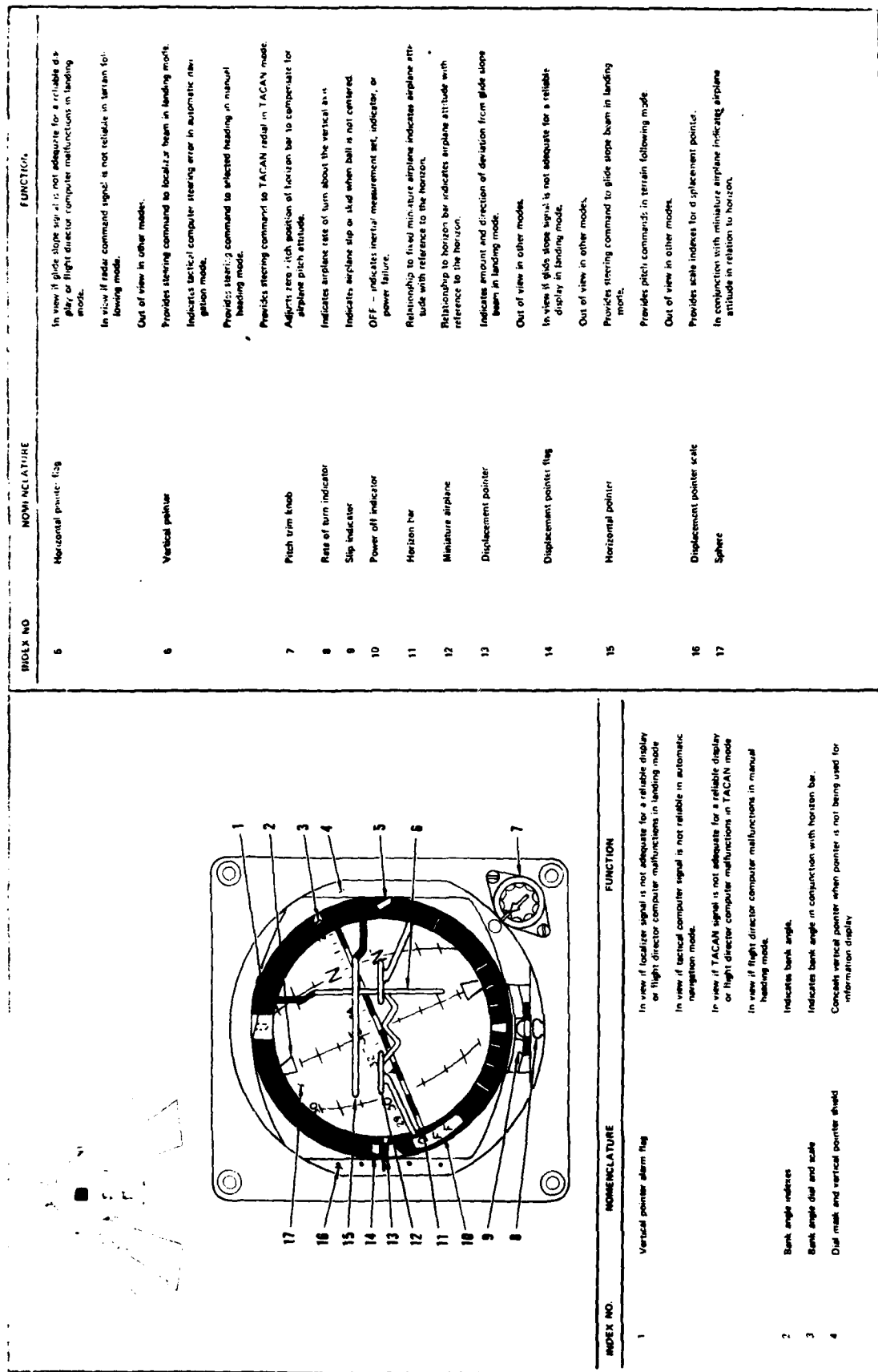


Figure 99 Heading Mode System Altitude Director Indicator Controls And Indicator

HEAD UP-DISPLAY (HUD) CONTROLS

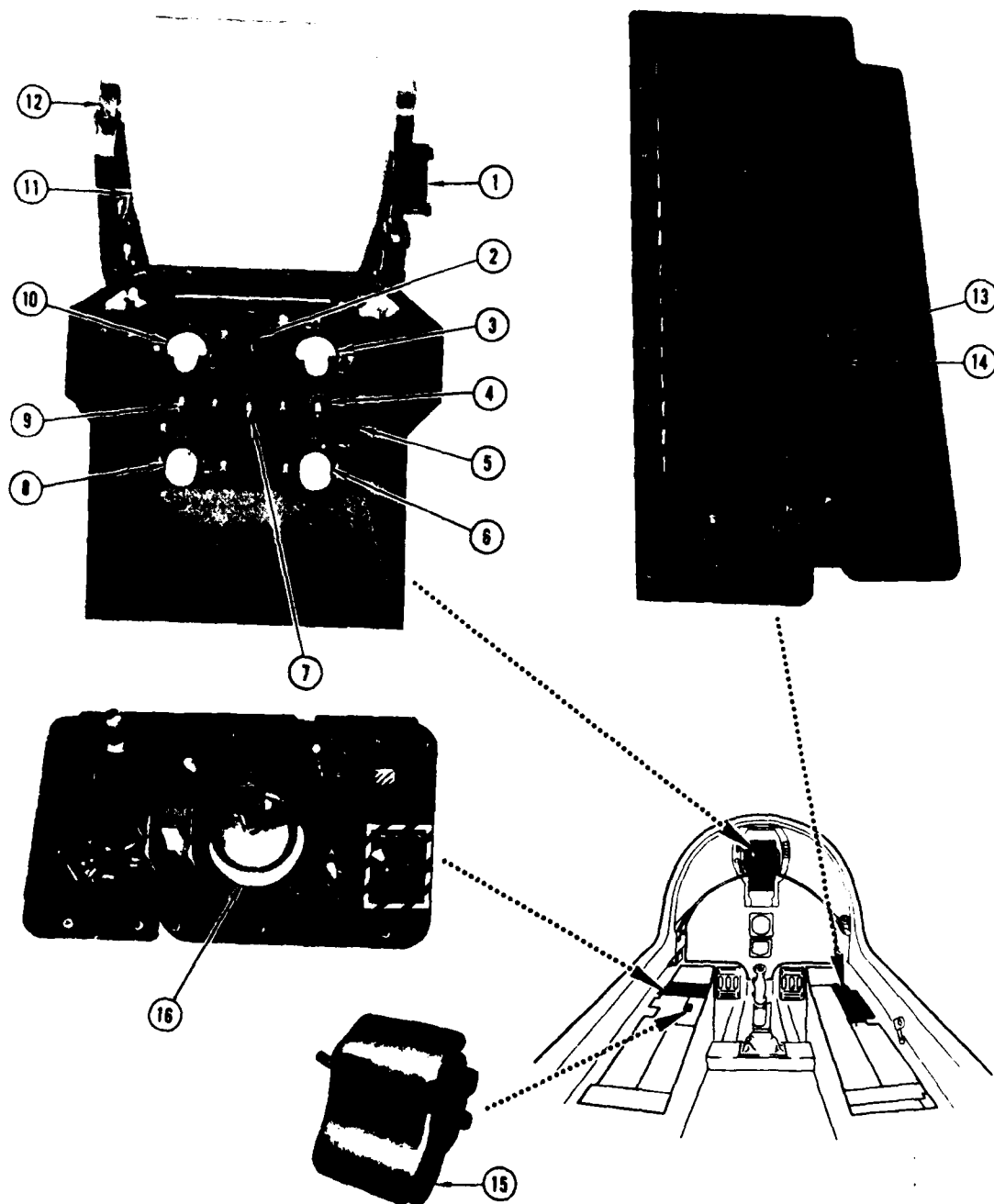
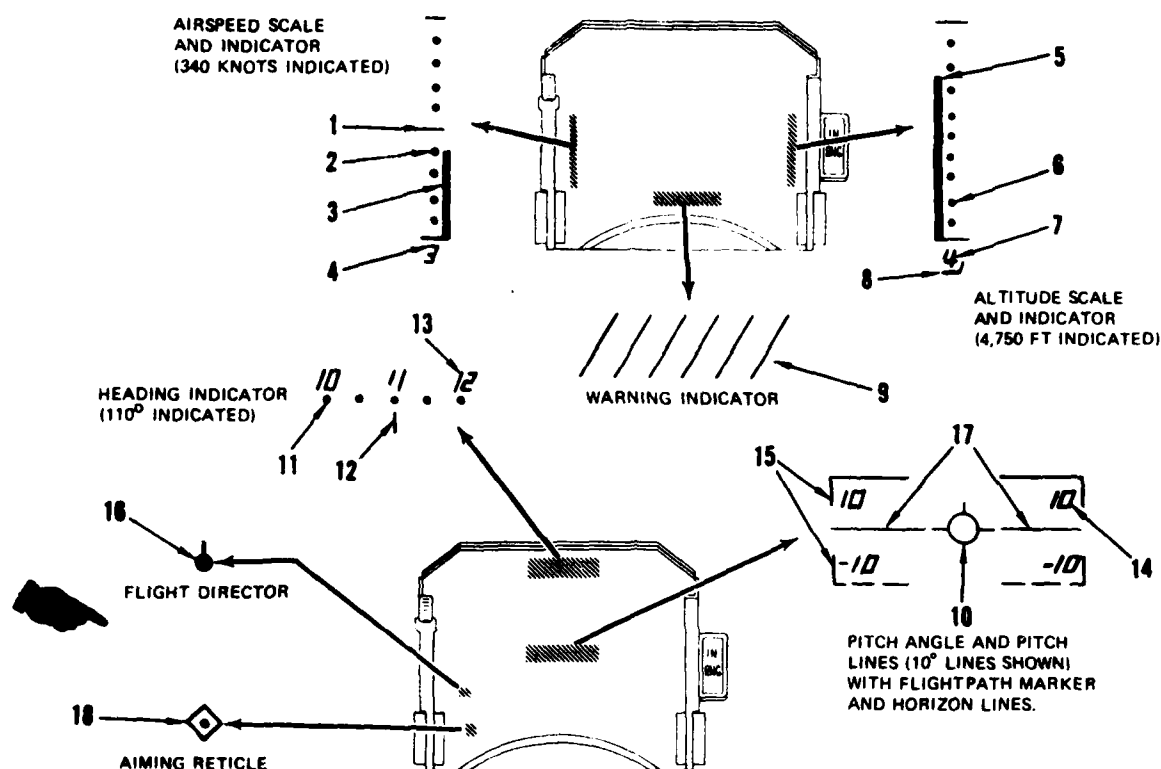


Figure 100a Head Up Display (HUD)
Controls

HEAD-UP DISPLAY (HUD) CONTROLS

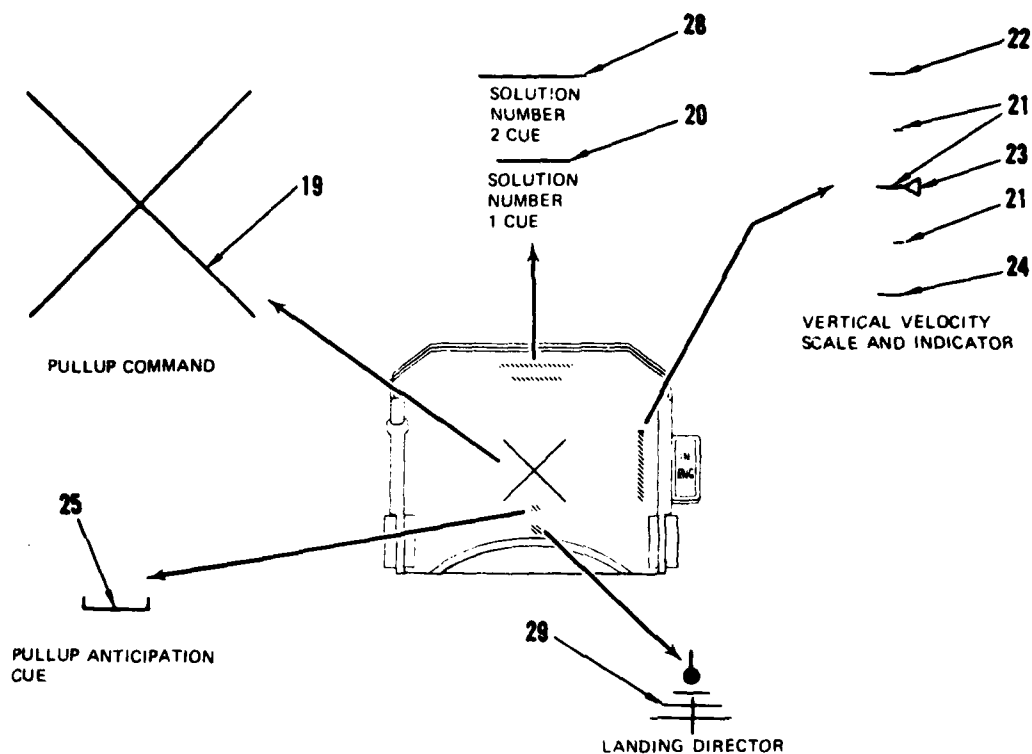
Control Label	Function
1. IN RNG indicator	On (IN RNG) — indicates when aircraft is within a preselected range of target. Range is set on the RANGE SET thumbwheel control on left console.
2. PNL LTS switch	PNL LTS — turns on HUD panel lights. OFF — turns off HUD panel lights.
3. STBY RETICLE power and brightness control	BRT — Clockwise rotation increases standby reticle brightness. OFF — full counterclockwise rotation turns off standby reticle lamps.
4. TEST switch	TEST — initiates built-in self-test. OFF — disconnects self-test.
5. MILS indicator	Indicates depression angle of standby reticle in milliradians.
6. Standby reticle depression knob	DEPR — clockwise rotation adjusts the standby reticle depression angle from zero to optical reference axis to 210 mils. Two detent positions are provided, one at the zero position and one at approximately 87 mils.
7. BARO ALT/RDR ALT switch	BARO ALT — causes barometric altitude to be displayed on the altitude scale. RDR ALT — causes radar altitude to be displayed on the altitude scale when below 5,000 feet, and causes an index mark to be displayed to the lower right of the scale numeral.
8. FILTER knob	DAY — removes night filter from field of view. NIGHT — inserts filter in front of lens.
9. SCALES switch	SCALES — displays airspeed, altitude, vertical velocity, and heading symbology. OFF — removes scales from display.
10. HUD power and brightness control	BRT — clockwise rotation increases symbol brightness. OFF — full counterclockwise rotation turns off the HUD except for the standby reticle.
11. Combiner glass	Reflects HUD symbols from cathode ray tube into pilot's line of vision.
12. Combiner position lever	Permits fore and aft movement of combiner glass. Glass is moved toward pilot in landing mode to enable better view over aircraft nose. Position optional in other modes.
13. HUD FAIL caution light	On (HUD FAIL) — indicates HUD system failure.
14. HUD HOT caution light	On (HUD HOT) — indicates a thermal overload within the system. Continued operation under this condition will result in complete system failure.
15. Thumbwheel control (RETICLE SLEW)	Permits movement of HUD aiming symbol along bombfall line in range only.
16. Bullpup controller	Permits movement of HUD aiming symbol in range and azimuth.

Figure 100b



INDEX NO.	NOMENCLATURE	FUNCTION
1	Index lines	Divide airspeed indicator into 50-knot increments.
2	Index dots	Divide airspeed indicator into 10-knot increments.
3	Airspeed column	Rises on increasing airspeed through intervals of 100 knots.
4	Airspeed numeric	Indicates airplane airspeed in intervals of 100 knots.
5	Altitude column	Rises on increasing altitude through intervals of 1,000 feet.
6	Index dots	Divide altitude indicator into 100-foot increments.
7	Altitude numeric	Indicates airplane altitude in intervals of 1,000 feet.
8	Radar altitude advisory symbol	Indicates altitude switch is in RDR ALT.
9	Warning lines	Flashes concurrently with the master caution light, comes on steady concurrently with the fire warning light.
10	Flightpath marker	Represents the flightpath of the airplane.
11	Index dots	Divide the magnetic heading indication into 5° increments.
12	Lubber line	Index for airplane heading.
13	Heading numeric	Indicates airplane heading. (Scale is times 10°.)
14	Pitch angle numeric	Indicates airplane pitch angle. (Scale is times 1°.)
15	Pitch angle lines	Airplane pitch axis index. (End tabs point in direction of horizon.)
16	Flight director	Indicates the relative position of an optimum flightpath.
17	Horizon lines	Represents relative position of horizon to the airplane pitch and roll axes.
18	Aiming reticle	An adjustable aiming or fix point reference indicator.

Figure 100c

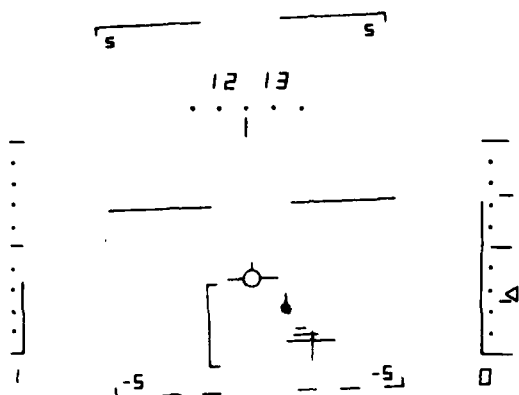


INDEX NO.	NOMENCLATURE	FUNCTION
19	Pullup command	Flashes on to indicate an immediate pullup requirement.
20	Solution number 1 cue	Symbol moves down to indicate an approaching weapon release point.
21	Index lines	Divides the vertical velocity scale into 500-foot increments.
22	Upper index line	Full scale climb index marker.
23	Vertical velocity pointer	Indicates vertical velocity.
24	Lower index line	Full scale dive index marker.
25	Pullup anticipation cue	Symbol moves up to indicate an approaching pullup requirement.
26	Deleted	
27	Deleted	
28	Solution number 2 cue	Symbol moves down the bombfall line to indicate an approaching weapon release point.
29	Landing director	Indicates the relative position of the landing flightpath during a landing approach.

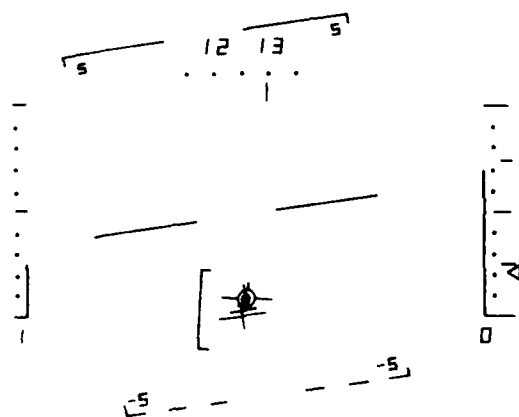
Figure 100d

HUD SYMBOLOGY

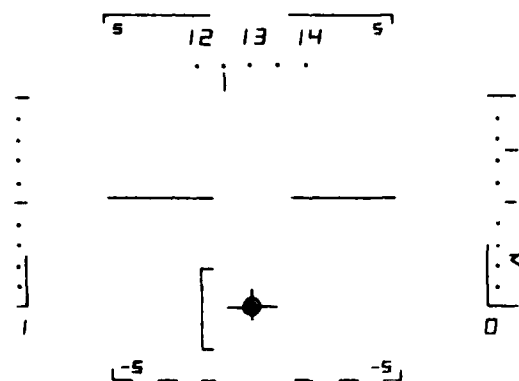
LANDING MODE



1. Approach too flat.
2. Perspective lines indicate that aircraft is above glide slope and left of centerline.
3. Angle of attack is less than the optimum value of 17.5 units.
4. Airspeed too fast.
5. Landing Director positioned below and right of FPM represents a command to turn right and increase sink rate to effect glide path intercept.



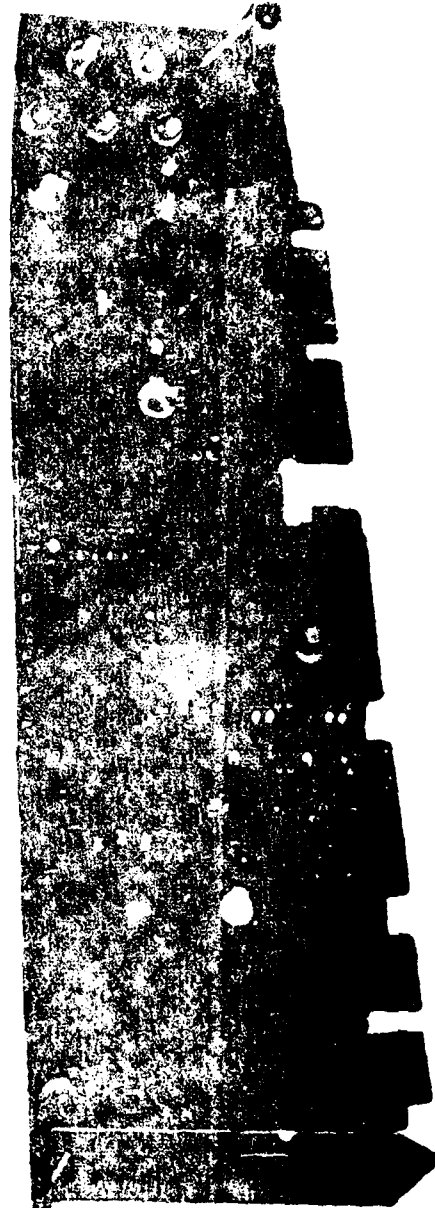
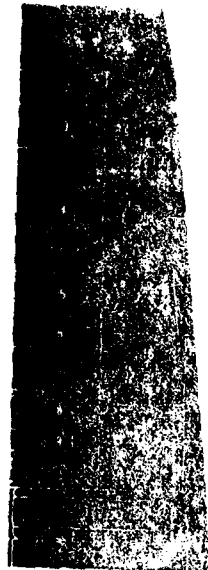
1. Pilot responds by reducing power, increasing angle of attack and banking right.
2. Landing Director centered in the FPM indicates that the pilot has initiated the proper control movements to effect glide path intercept.
3. Perspective lines indicate that aircraft is situated above glide slope and to the right of centerline.
4. Angle of attack is approaching the optimum value of 17.5 units.



1. Aircraft is on glide path with proper sink rate.
2. Angle of attack is optimum at 17.5 units.

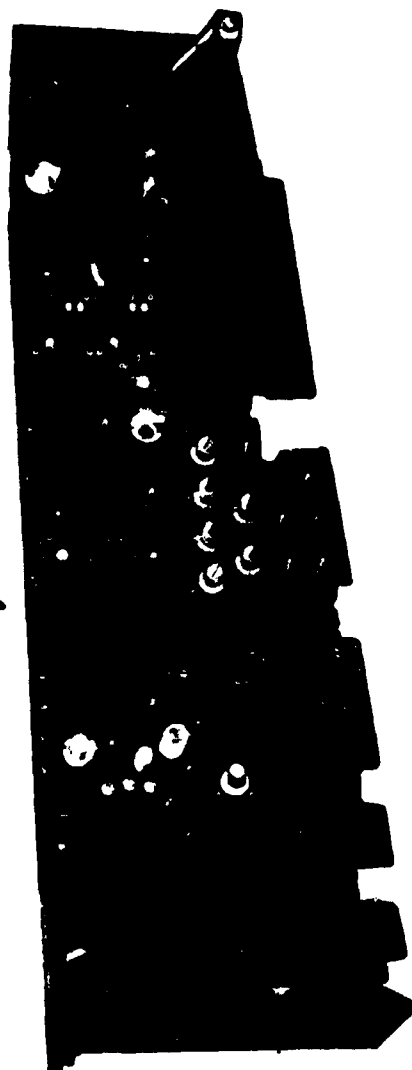
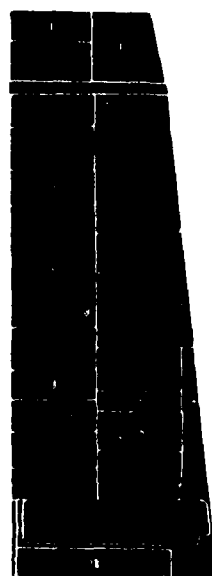
Figure 100e

RIGHT CONSOLE 16 18 - 26



1. INTERIOR LIGHTS control panel
2. DOP control panel
3. OXYGEN REGULATOR
4. NAV WD control panel
5. TACAN control panel
6. ILS control panel
7. FM COMM control panel
8. Speech security control panel
9. RADAR BEACON control panel
10. Blank panel
11. WINGFOLD
12. Map case
13. Blank panel
14. AIR COND control panel
15. IMS control panel
16. ECM pod control panel
17. EXT LIGHTS controls
18. ADVISORY and CAUTION light

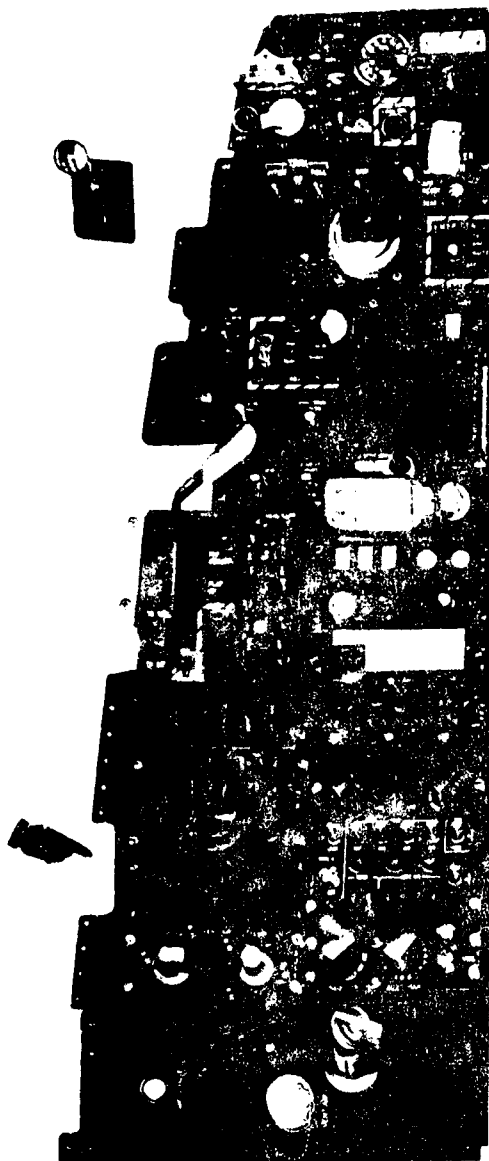
RIGHT CONSOLE [17] [27]



1. Hydraulic pressures indicators
2. Oxygen pressure and TRUE
AIRSPEED indicators
3. DOP control panel
4. OXYGEN REGULATOR
5. ECM pod control panel
6. NAV WD control panel
7. TACAN control panel
8. ILS control panel
9. IMS control panel
10. Speech security control panel
11. HOOK control panel
12. ADVISORY and CAUTION
lights panel
13. INT and EXT lights control panel
14. FM COMM control panel
15. RADAR BEACON control panel
16. AIR COND control panel
17. WINGFOLD
18. MAP CASE

Figure 102 Right Console [17] [27] +

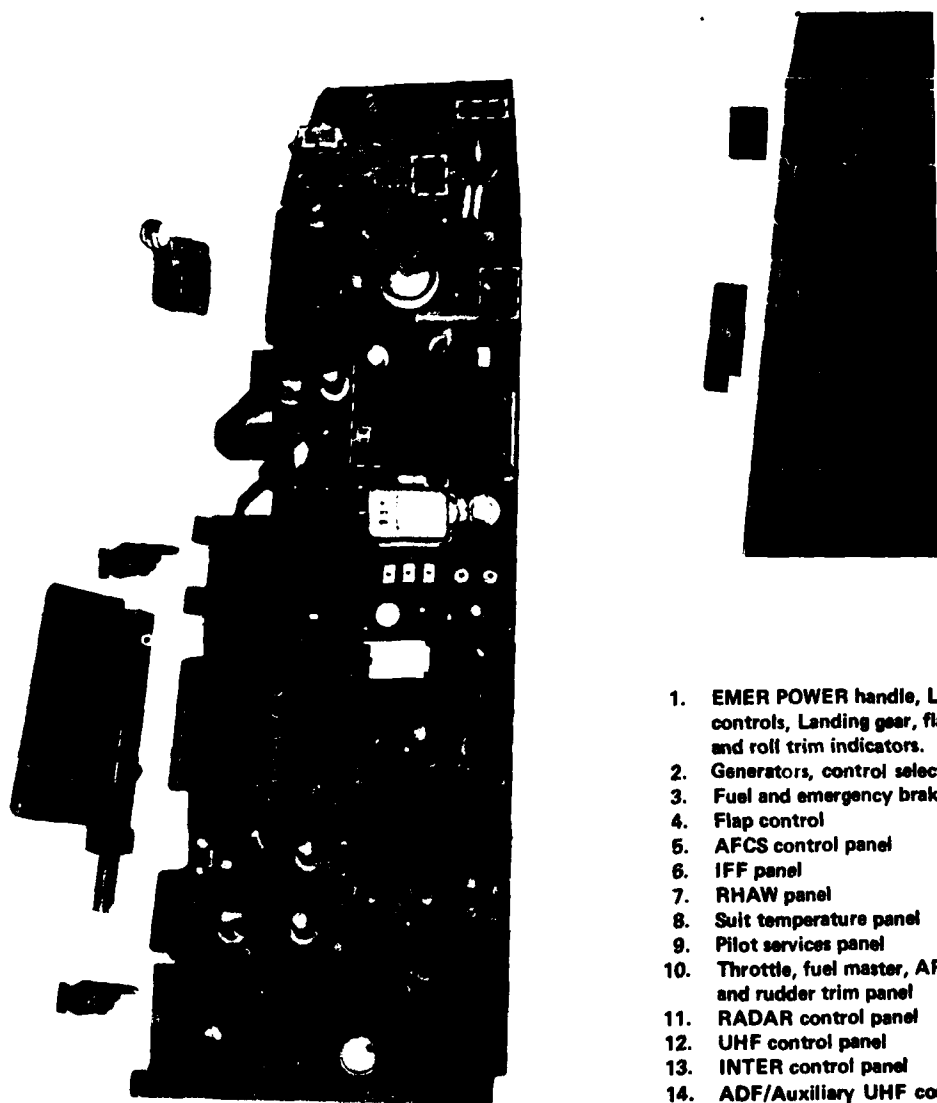
LEFT CONSOLE → [16] [18] → [26]



1. Emergency power, EMER WHLS DN, PITCH, ROLL and YAW trim indicators
2. Generators, control selector panel
3. Fuel and emergency brake panel
4. Flap control
5. AFCS control panel
6. TER CLR/RANGE SET control
7. INTER control panel
8. DOUBLE DATUM lockout switch
9. Suit temperature panel
10. Pilot services panel
11. ADF radio control panel
12. IFF control panel
13. UHF radio control panel
14. RADAR control panel
15. Throttle, fuel master, rudder trim panel
16. Canopy jettison control handle (on left longeron)

Figure 10 Left Console [16] [18] → [26]

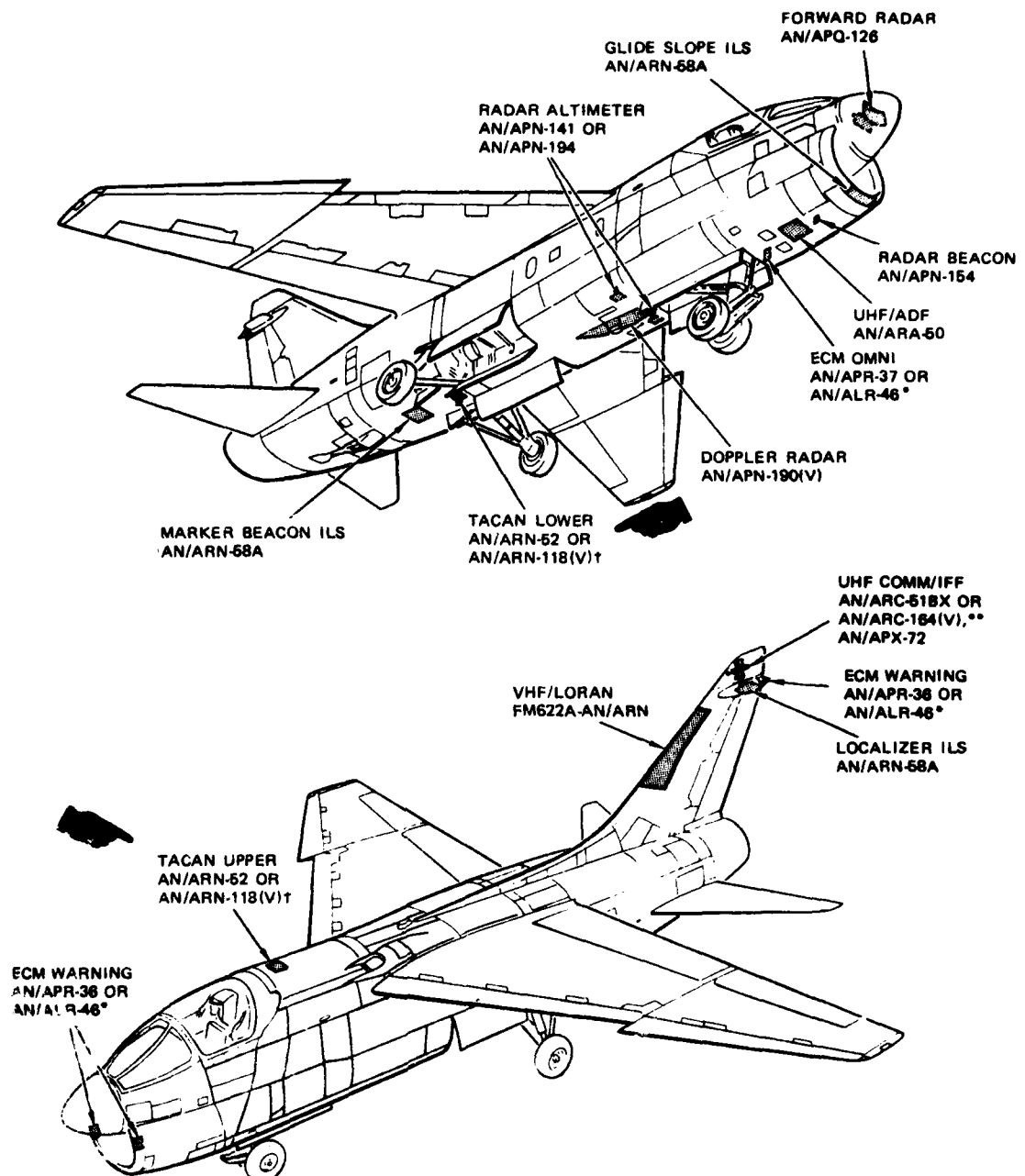
LEFT CONSOLE 17 27



1. EMER POWER handle, Landing gear controls, Landing gear, flaps, and pitch and roll trim indicators.
2. Generators, control selector panel
3. Fuel and emergency brake panel
4. Flap control
5. AFCS control panel
6. IFF panel
7. RHAW panel
8. Suit temperature panel
9. Pilot services panel
10. Throttle, fuel master, AR door, and rudder trim panel
11. RADAR control panel
12. UHF control panel
13. INTER control panel
14. ADF/Auxiliary UHF control panel
15. DOUBLE DATUM lockout switch
16. ALTERNATE FUEL FEED panel (on left longeron)
17. CANOPY JETTISON CONTROL HANDLE (on left longeron)

Figure 101 Left Console 17 27 +

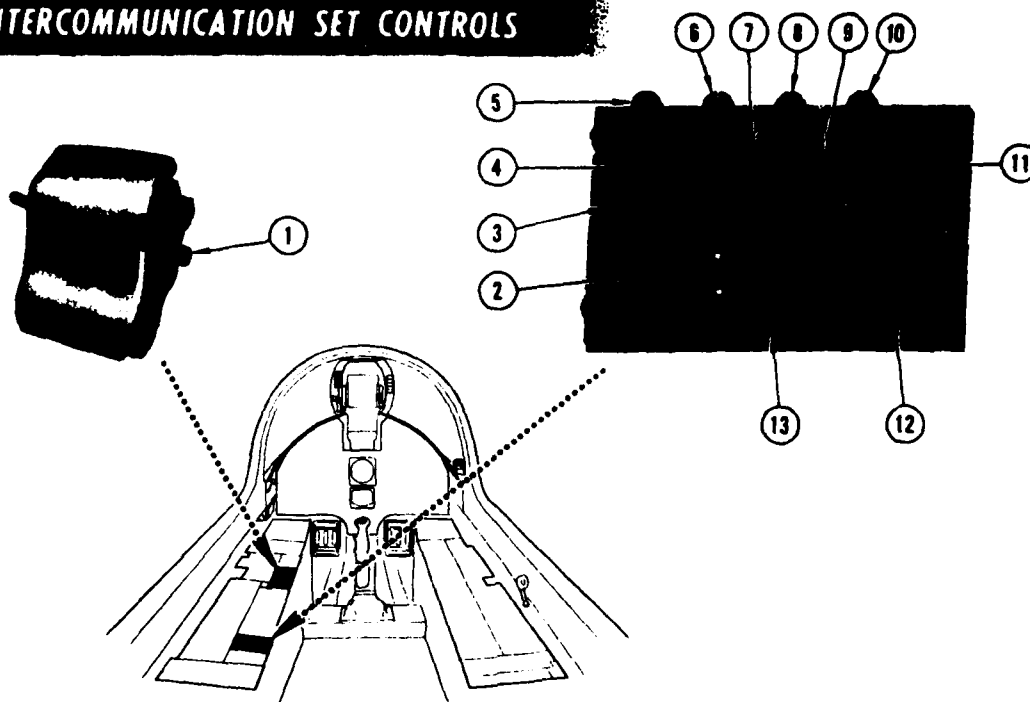
ANTENNA LOCATIONS



* Aircraft after T.O. 1A-7D-780 have the AN/ALR-46 system installed.
 † Aircraft after T.O. 1A-7D-785 have the AN/ARN-118(V) TACAN installed.
 ** Aircraft after T.O. 1A-7D-808 have the AN/ARN-118(V) TACAN installed.

Figure 105 Antenna Locations

INTERCOMMUNICATION SET CONTROLS



1. MIKE button	Pressed — activates microphone. Also actuates IFF identification replies with IFF in MIC mode.
2. VOL control knob	Adjusts volume of all incoming signals simultaneously.
3. HOT MIC switch	Pulled Out — enables operator to talk to ground crew without depressing MIKE button. Pushed In — disables HOT MIC function.
4. TACAN monitor knob	Pulled Out — connects TACAN station identification signals to headset. Rotated — adjusts volume. Pushed In — disconnects TACAN audio.
5. INTER monitor knob	Pulled Out — connects ground intercom station audio to headset. Rotated — adjusts audio volume. Pushed In — disconnects intercom audio.
6. UHF monitor knob	Pulled Out — permits UHF radio to be monitored while panel selector switch is in VHF or INT. Rotated — adjusts audio volume. Pushed In — disconnects UHF audio (UHF audio continues to be received if UHF is selected on panel selector switch).

Figure 106

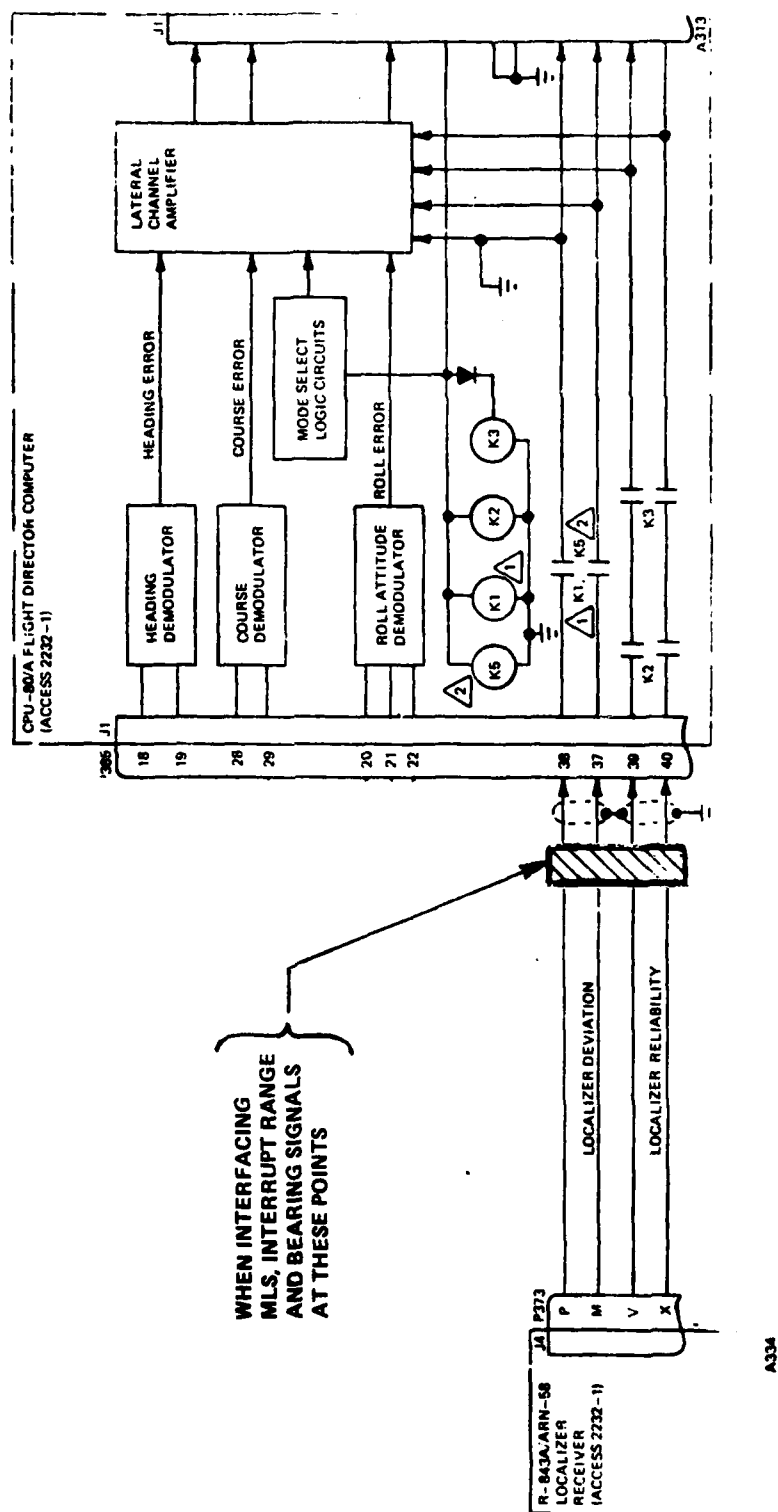


Figure 107 Localizer Receiver/Flight Director Computer Interface

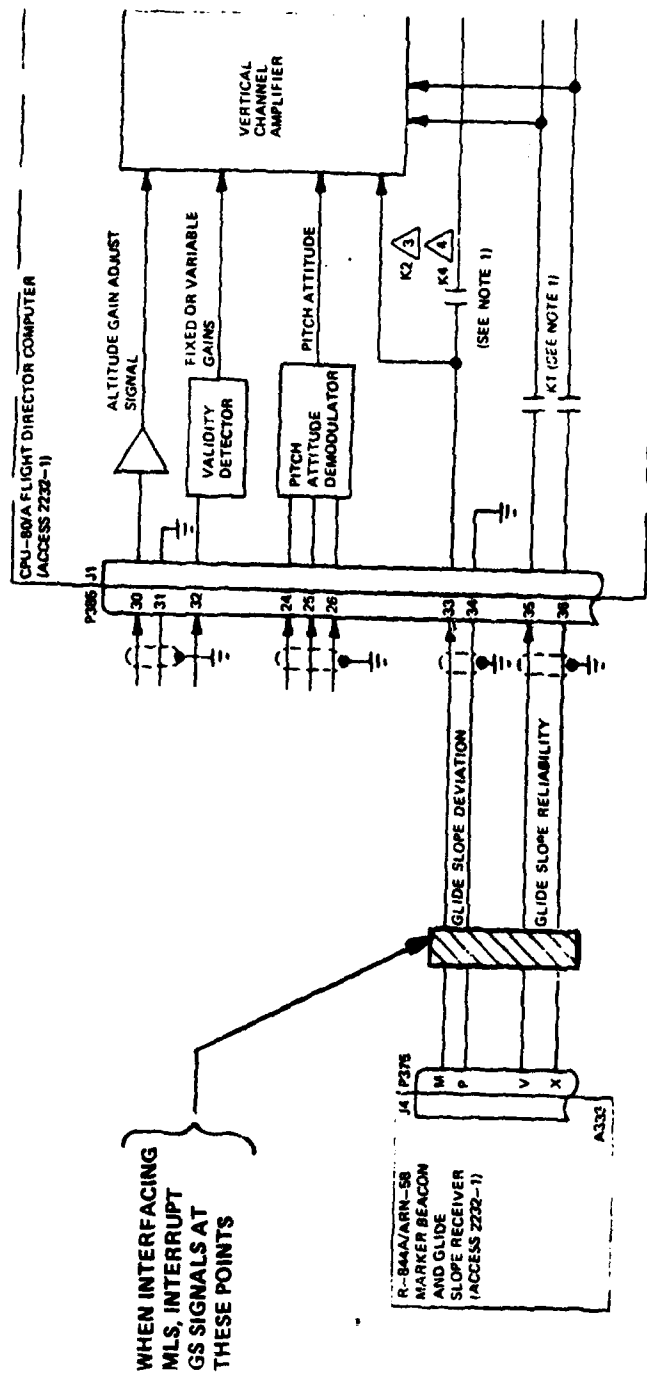


Figure 108 GS Receiver/Flight Director Computer Interface

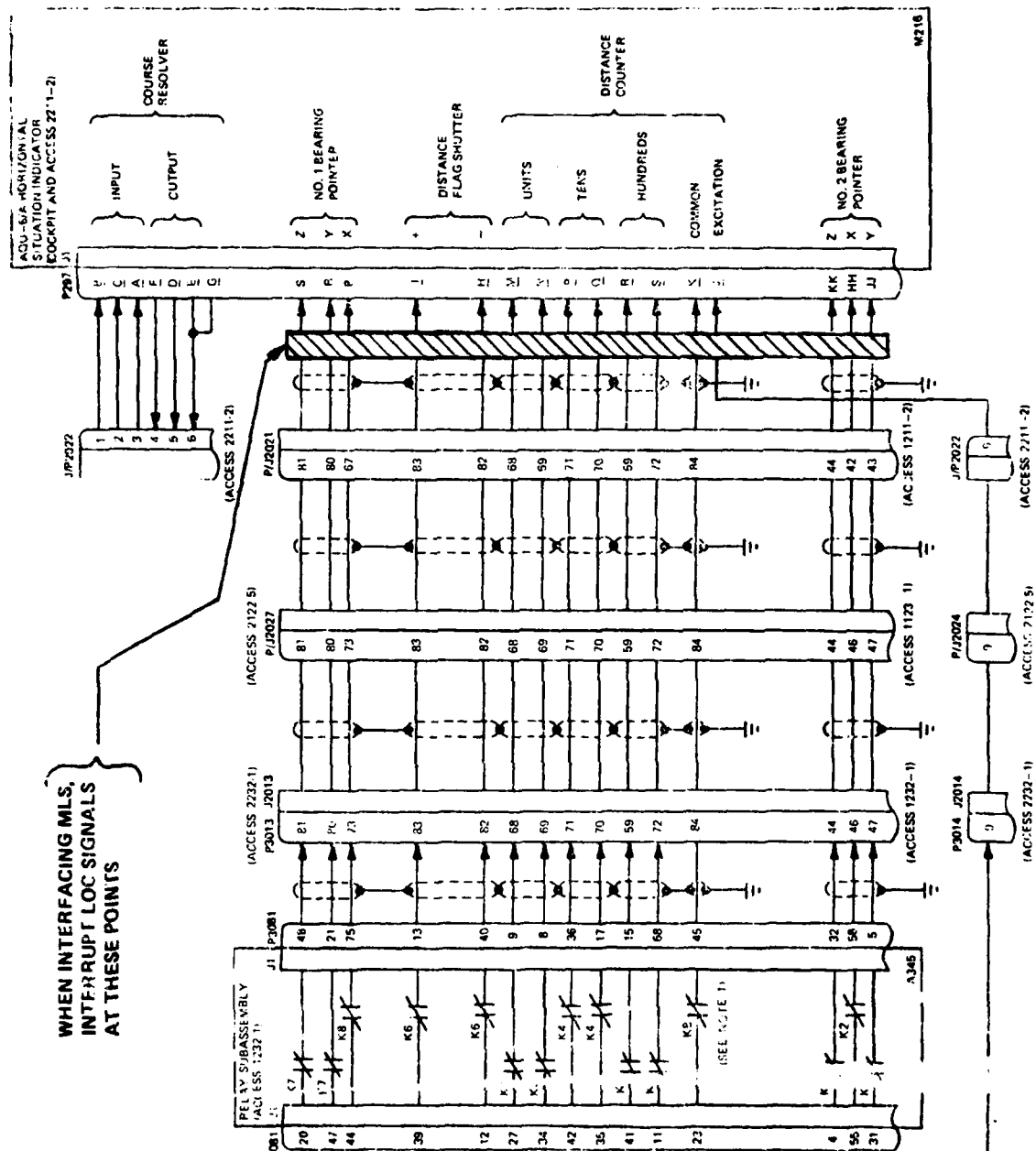


Figure 109 HSI/Range/Bearing Interface

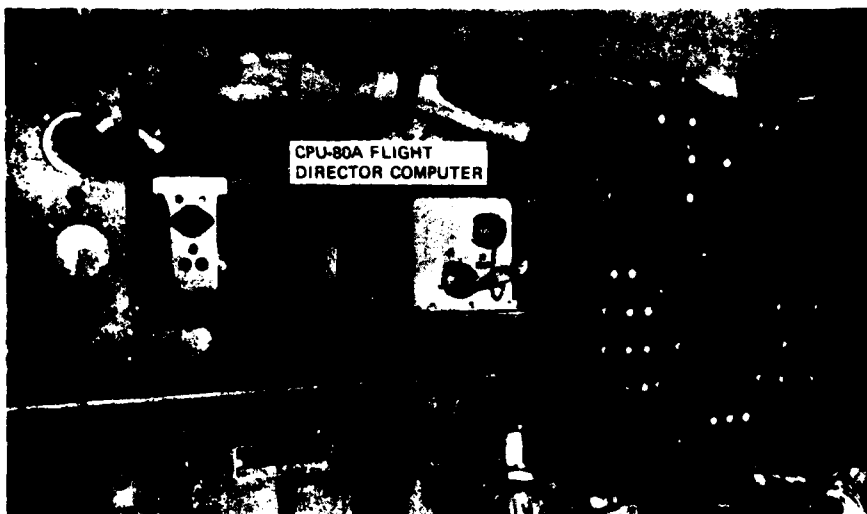
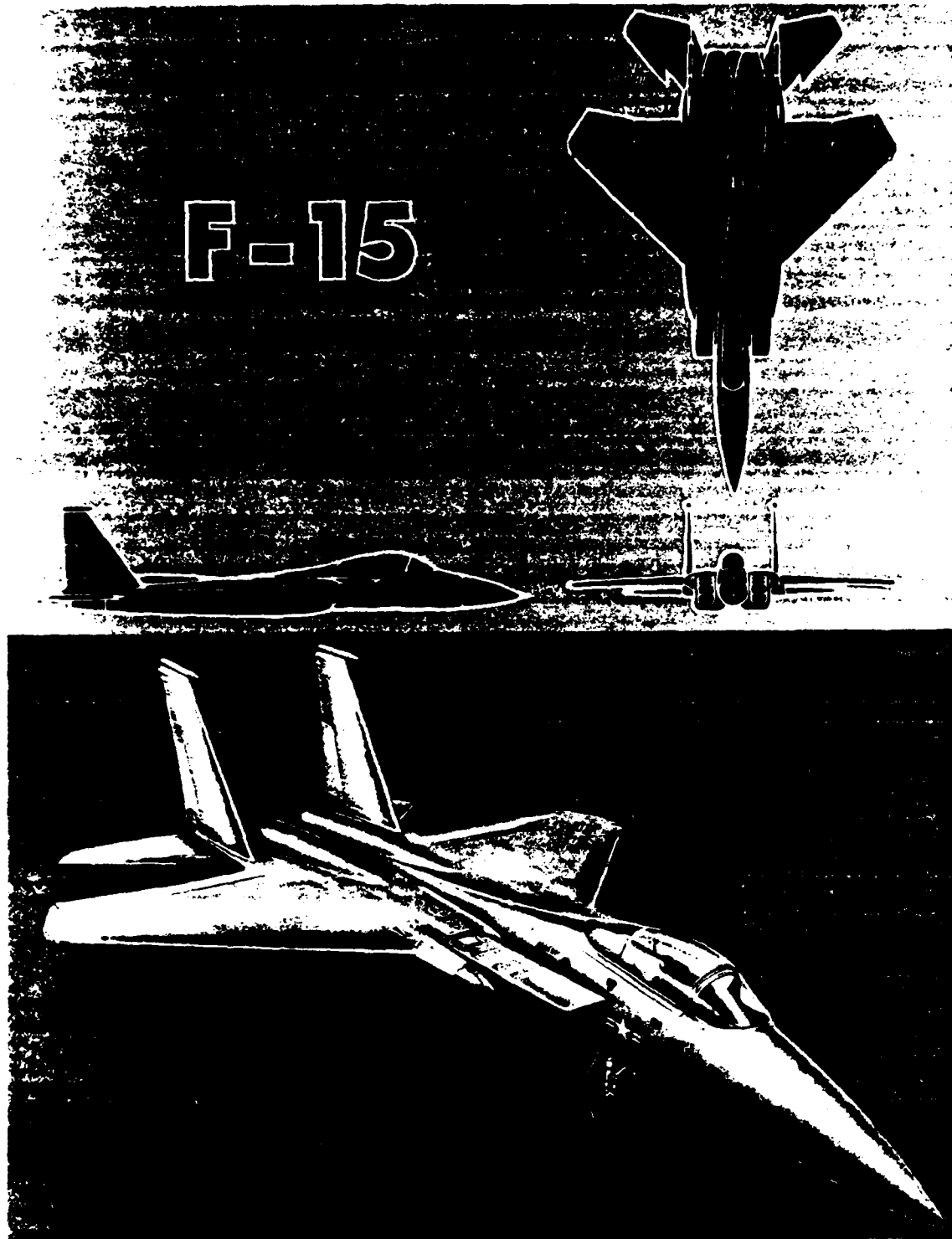


Figure 110 CPU-80A Flight Director Computer

MLS CONSIDERATIONS



5.5 F-15A

5.5.1 General F-15A Information

The F-15 is a high-performance, supersonic, all-weather air-superiority fighter built by McDonnell Aircraft Company. Its primary mission is aerial combat, but it can also perform ground attack missions. Radar and heat seeking air-to-air missiles and a 20 MM gun are the primary armament. The cockpit is elevated to enhance visibility. Major aircraft systems are designed and conveniently located for high maintainability and reliability.

The avionics equipment aboard the aircraft is integrated and provides weapon delivery, aerial combat, and navigation capabilities. Navigation and associated equipment considered for the MLS interface analysis is as follows:

- TACAN Interrogator
- ILS Receiver (LOC/GS)
- ILS/TAC Control Panel
- Flight Director Adapter
- Central Computer
- Horizontal Situation Indicator (HSI)
- Attitude Indicator (AI)
- Integrated Communication System
- HUD System
- Steering Switch
- ADI Switch

A Block diagram of the existing ILS mode interface is illustrated in Figure 111. Only those elements involved with the MLS installation or possible MLS usage are included. As shown, signals from the ILS receiver and logic from the Steer Mode switch are applied to the Flight Director Adapter. This unit in turn provides deviation and reliability signals to the Central Computer, HSI, and ADI. The Central Computer combines the deviation and other signals and computes pitch and roll steering signals for localizer and glideslope flight path control.

Computed steering signals from the Central Computer are applied to the HUD Data Processor and Flight Director Adapter, and these elements, in turn, provide the steering commands for the

HUD and ADI respectively. In addition, the Central Computer provides converted, localizer and glideslope, deviation and reliability signals to the HUD Data Processor for display on the HUD.

The ILS mode is activated by placing the steering mode switch to the ILS/NAV position (see Figure 112, upper left). As a result, ILS, deviation reliability, and steering signals are applied to the ADI and HSI. To present the same information on the HUD, the ADI switch (see Figure 113, Ref. No. 8) must be activated.

The only annunciation available during an ILS approach is the position (ILS/NAV) of the steering mode switch. An indication is available on the HUD (provided that the ADI pushbutton is activated) when the ILS/NAV mode is selected.

The legend "CSET" flashes on the HUD for 10 seconds to remind the pilot to set the final approach course (via the HSI course set knob). At the end of 10 seconds, "CSET" is replaced with "GSUP" or "GSDN". Interception of glideslope and automatic shift to the approach mode is indicated by extinguishing of the GSUP or GSDN light and by glideslope indications on the HUD and ADI. Except for the above, the only other approach annunciations are provided by the positions of the steering and ADI ILS switches.

On an ILS approach, use of the ILS function is not recommended until approximately aligned with the final approach heading. Bank Steering information on the HUD and ADI automatically switches from 30° maximum bank angle to the final approach mode of 15° maximum bank angle when the glideslope is intercepted. If the glideslope is intercepted with a considerable difference between aircraft heading and final approach course, a 15° bank angle may not be sufficient to align the aircraft on final approach.

Since the ILS system is non-redundant, the F-15 is a Category I aircraft. ILS approaches can be made only by utilizing the integrated Flight Director System. The autopilot (flight control system) provides three axis control augmentation and pitch and roll attitude hold (pilot relief) modes. Autopilot navigation and approach coupling is not available.

Most of the F-15A avionics is implemented, using digital techniques for the majority of unit interfaces, internal computations, and logic. The ILS receiver outputs, AI, and the inputs to the certain functions of the HSI are analog interfaces. The Flight Director Adapter (FDA) does not provide any computations. It functions only as a converter (A/D and D/A) for interfacing with the Central Computer which does all the flight path computations associated with the navigation modes. In addition, the FDA provides the switching which couples the selected references to the AI and HSI.

The Central Computer is a high speed, stored program digital computer which communicates with the ILS-related equipment via data buses. This unit provides ILS, deviation, steering, and reliability signals for the HUD system and computed ILS steering signals, via the FDA, for the AI.

A typical F-15 cockpit layout is illustrated in Figures 114a B and C. The AI and HSI displays are located on the lower center of the instrument panel. Mounted above the instrument panel is the Heads-Up Display. These three displays are used during ILS approaches in conjunction with the ILS receiver, FDA and Central Computer.

Functional details of the HSI, AI and HUD are illustrated on Figures 115 and 116. See Figure 112 for typical approach symbols displayed on the HUD during an ILS approach.

5.5.2 F-15A MLS Recommendations

Since the F-15A must operate at forward air bases like the A-7D, an MLS-3 (Selected Intercept of Final) configuration capability is highly desirable. For reasons similar to those previously discussed for the A-7D, a full complex trajectory configuration cannot be recommended and even a recommendation of MLS-3 is questionable. Workload levels involved for complex trajectory flight are prohibitive for the operator of a single-seat aircraft flying at high approach speeds without autopilot coupling. Also, space and weight restrictions on the aircraft may preclude the addition of the units required for MLS-3. If subsequent studies indicate that the workload levels associated with this configuration are acceptable, and if space and weight limitations are not a problem, the MLS-3 configuration should be incorporated in the F-15A. If any of these final studies reveals a serious problem, MLS-1 (Direct ILS Replacement)

should be considered. The following paragraphs describe installation guidelines for the MLS-1 and MLS-3 configurations in the F-15A.

Installation of an MLS-1 system in the F-15A type aircraft involves the addition of the following units:

<u>UNIT</u>	<u>QTY.</u>
MLS Angle Receiver	1
MLS Switching Unit	1
MLS-1 Tuner	1
MLS Angle Antenna	1

The first two units are remotely located and these can be accommodated in various aircraft locations. Panel space is available on both the right and left consoles (see Figures 114b and 114c to mount the MLS-1 tuner in either location. The MLS antenna must be mounted in the general area of the present localizer and glideslope antenna (see Figure 117). Empty holes exist on the left bus circuit breaker panel (see Figure 118) to accommodate MLS circuit breakers.

Figure 119 is an illustration of the present ILS/Flight Director Adapter interface. The wires associated with the ILS receiver must be interrupted and routed through the MLS switching unit. This will result in analog raw data MLS information being used and displayed in exactly the same manner as is presently done for ILS.

Installation of an MLS-3 system in the F-15A involves the addition of the following units:

<u>ITEM</u>	<u>UNIT</u>	<u>QTY.</u>
1	MLS Angle Receiver	1
2	DME Interrogator	1
3	MLS NAV Coupler	1
4	MLS Switching Unit	1
5	MLS AZ/DME Display	1
6	MLS Tuner/Selector	1

<u>ITEM</u>	<u>UNIT</u>	<u>QTY.</u>
7	MLS Angle Antenna	1
8	DME ANTENNA (MLS)	1
9	Audio Panel Switches	1

Items 1 through 4 are remotely located in the avionics bay. If available space is critical, the following are alternate solutions to conserve space and reduce weight:

- Delete present ILS equipment completely and only accommodate MLS-3 (Probably not acceptable).
- Replace the existing Flight Director Adapter with a custom MLS NAV Coupler and modify the Central Computer to interface with this unit.
- Absorb the MLS NAV Coupler functions into the Central Computer (digital). This involves a program and I/O change as a minimum, but, more importantly, it is a major investigative effort to determine feasibility.
- If none of these alternate solutions is feasible, then only an MLS-1 (Direct ILS Replacement) configuration is applicable to the F-15 type aircraft.

If space, weight, and workload problems are not serious, MLS-3 can be installed. The display capability of the F-15A is certainly sufficient for presentation of the MLS-3 display parameters. As shown in Figure F15-5, the HSI, AI, and HUD provide for all of the functions described in Sections 4.1.2.3 and 4.1.2.4. Although cockpit space limitations on the main instrument panel appear to prohibit the addition of the MLS AZ/DME indicator, these parameters could be programmed for the HUD. Sufficient space can be found on the instrument panel for a small alert light.

AD-A096 593

BENDIX CORP TETERBORO N J FLIGHT SYSTEMS DIV

F/G 17/7

CONTROL-DISPLAY INVESTIGATION OF COMPLEX TRAJECTORY FLIGHT USIN--ETC(1

DEC 79 R JOHNSTON, W MEDLINSKI, H SCHMIER

F33615-77-C-2053

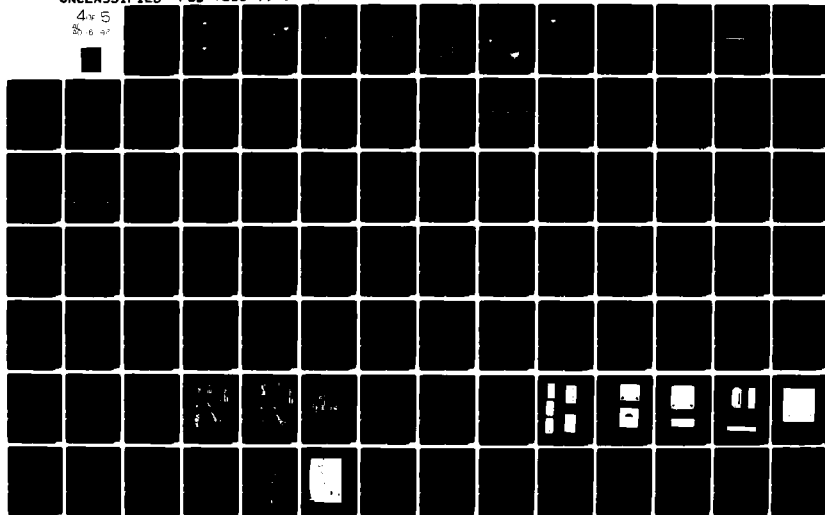
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FSD-7211-79-04

AFFDL-TR-79-3139

NL

4x5
25 6 47



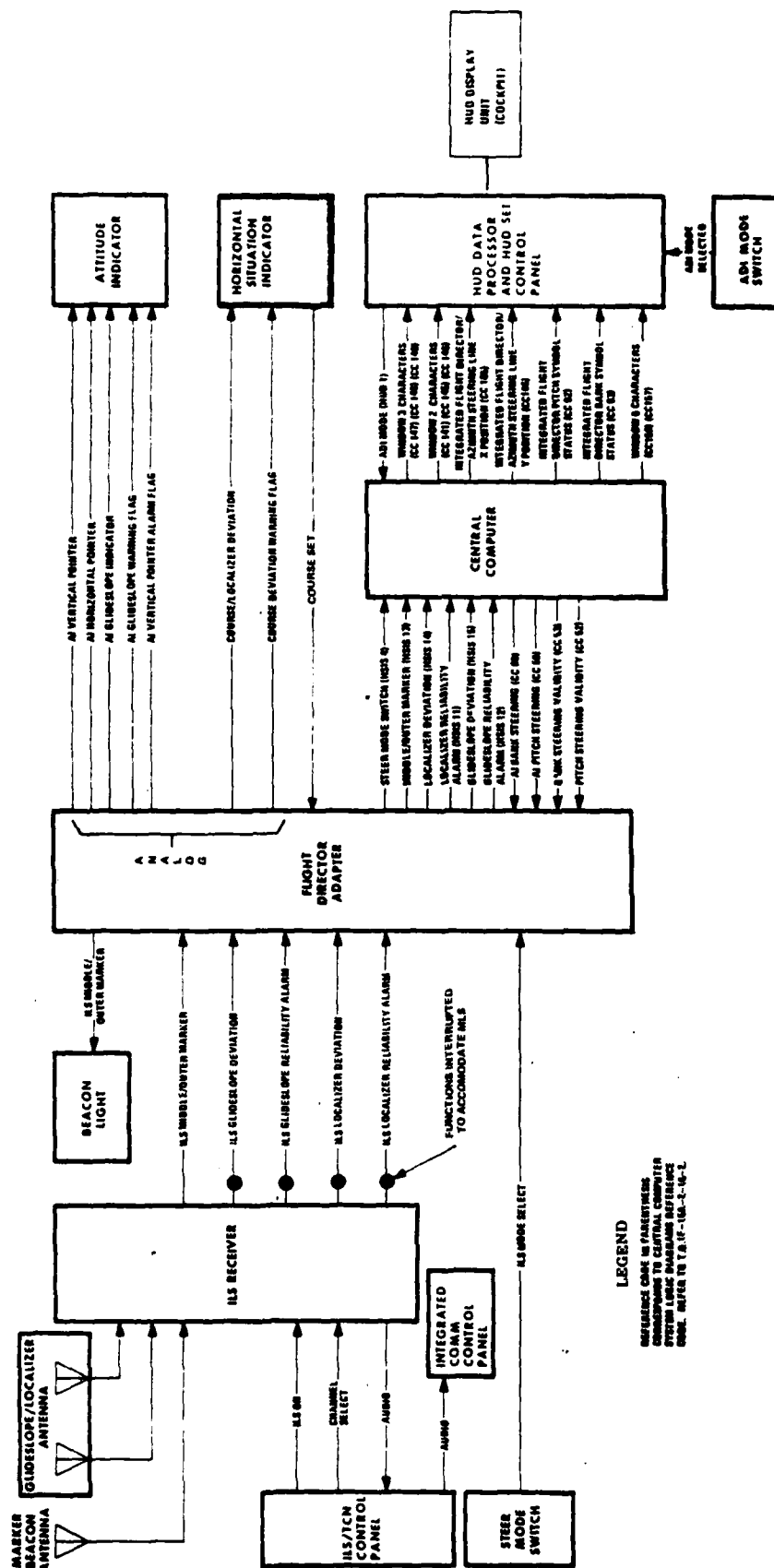
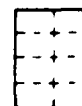
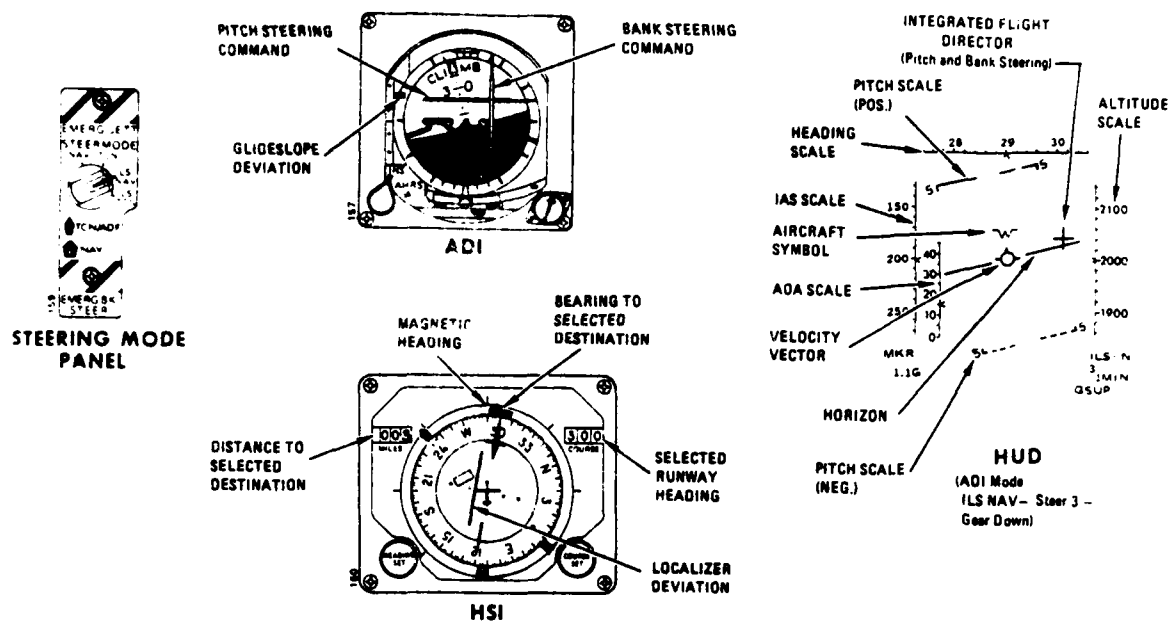


Figure 111 ILS Block Diagram F-15A

ILS/NAV AND ILS/TACAN MODE DISPLAYS



ILS/NAV



ILS/TACAN

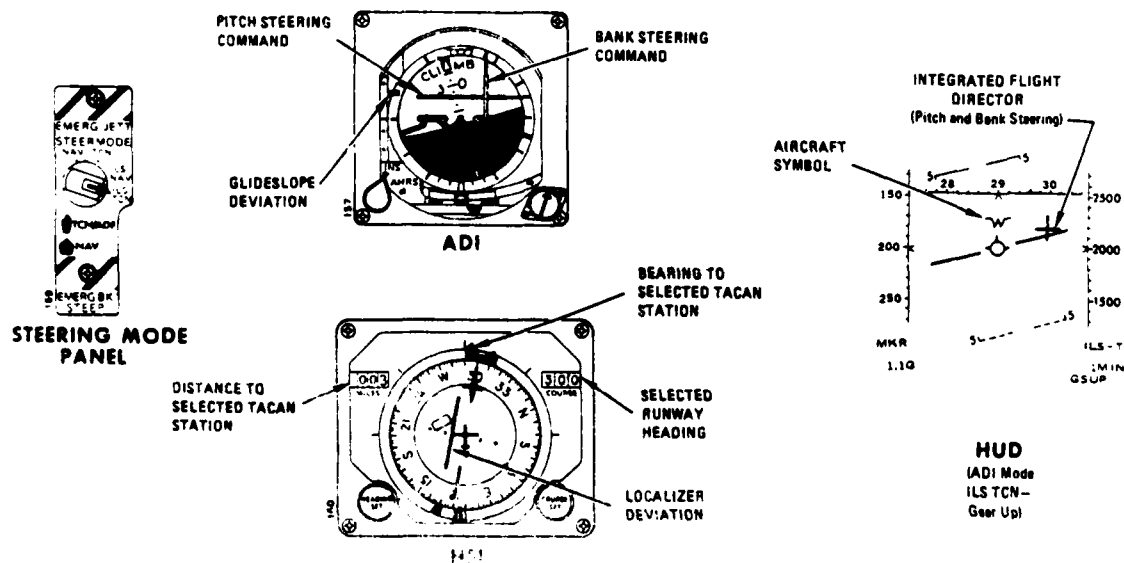


Figure 112 ILS/NAV and ILS/TACAN Mode Displays

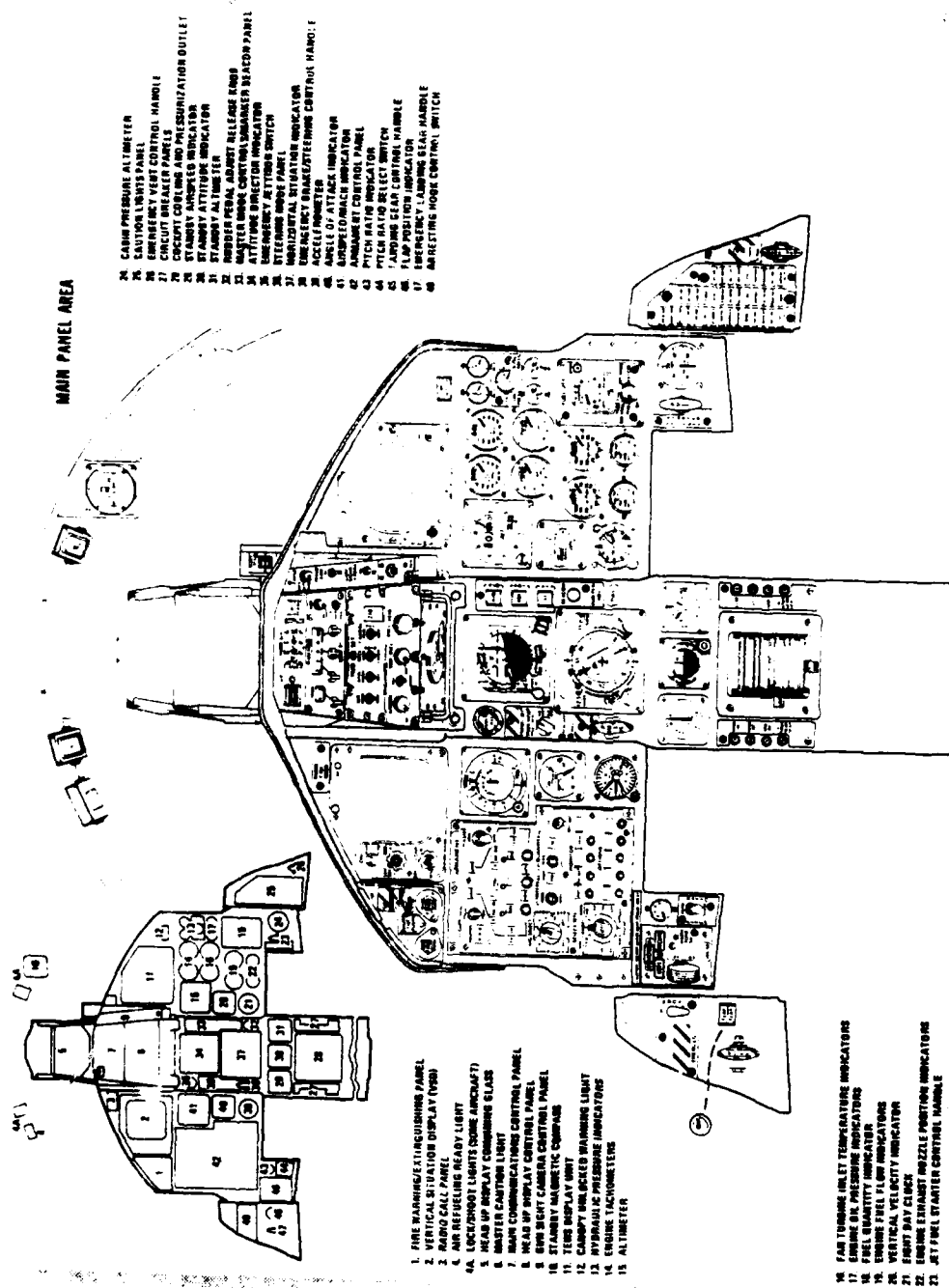
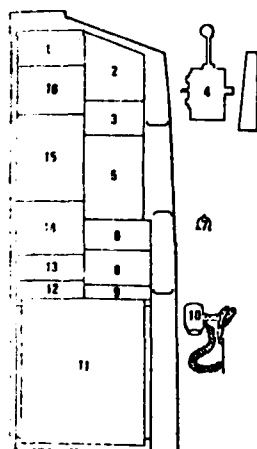


Figure 114a Main Panel Area

RIGHT CONSOLE AREA

1. OXYGEN REGULATOR
2. ECS PANEL
3. TEMPERATURE PANEL
4. CANOPY CONTROL HANDLE
5. INTERIOR LIGHTS CONTROL PANEL
6. TEWS POD CONTROL PANEL
7. OXYGEN HOSE STOWAGE FITTING
8. BLANK
9. ENGINE START FUEL SWITCHES
10. UTILITY LIGHT
11. STOWAGE COMPARTMENT
12. OXYGEN/COMMUNICATION OUTLET PANEL
13. COMPASS CONTROL PANEL
14. TEWS POWER CONTROL PANEL
15. NAVIGATION CONTROL PANEL
16. ENGINE CONTROL PANEL



**COCKPIT
TYPICAL**

PANEL SPACE
AVAILABLE

Figure 114b

LEFT CONSOLE AREA

1. ILS/TACAN CONTROL PANEL
2. CONTROL AUGMENTATION SYSTEM CONTROL PANEL
3. BLANK
4. THROTTLE QUADRANT
5. EXTERIOR LIGHTS CONTROL PANEL
6. INTEGRATED COMMUNICATIONS CONTROL PANEL
7. BLANK (F). TAKE COMMAND/ICS CONTROL PANEL, (TF)
8. BLANK
9. ANTI-G PANEL
10. BOARDING STEPS POSITION INDICATOR
11. BLANK
12. ARMAMENT SAFETY OVERRIDE SWITCH
13. GROUND POWER PANEL
14. BLANK
15. EMERGENCY AIR REFUELING HANDLE
16. SIT PANEL
17. INTERROGATOR CONTROL PANEL
18. IFF CONTROL PANEL
19. IFF ANTENNA SELECT SWITCH
20. TEWS PANEL
21. SEAT ADJUST SWITCH
22. RADAR CONTROL PANEL
23. VMAX SWITCH
24. BLANK
25. FUEL CONTROL PANEL
26. MISCELLANEOUS CONTROL PANEL
27. CANOPY JETTISON HANDLE

NOTE

- 1 (F) 77-0061 AND UP.
(TF) 77-0154 AND UP.

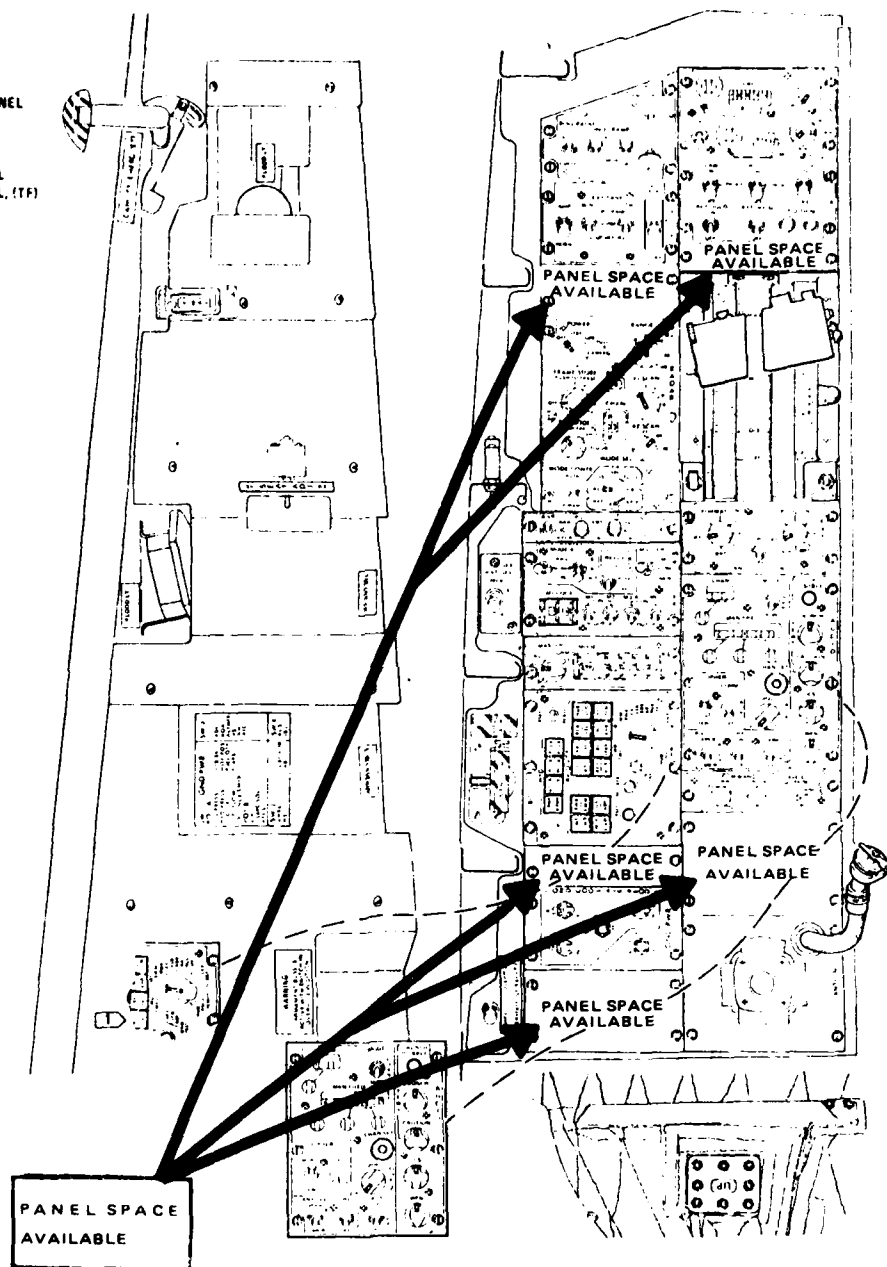
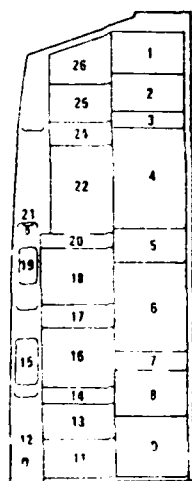


Figure 114c

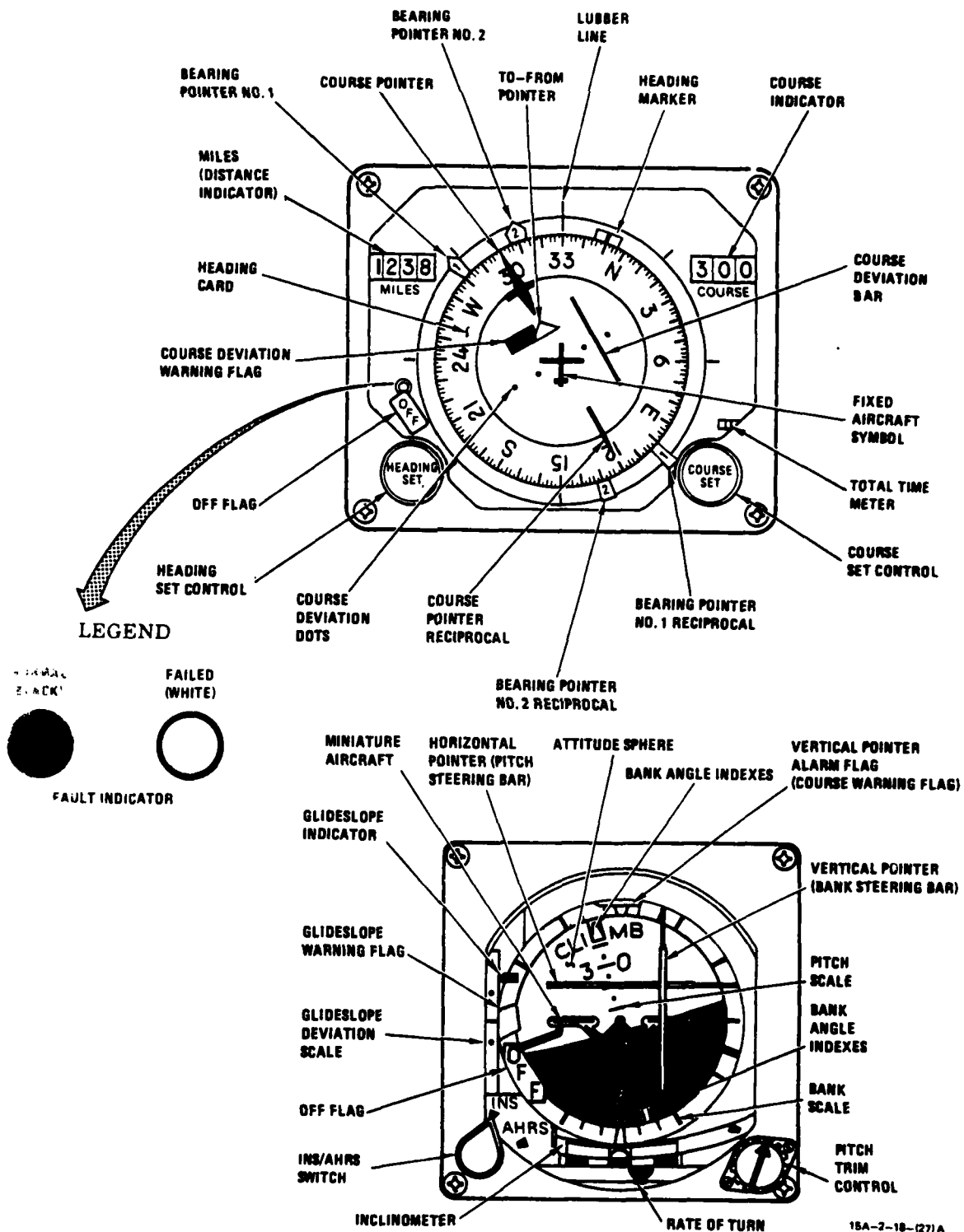
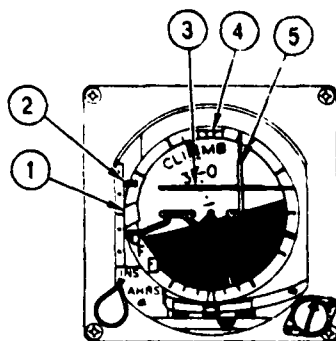
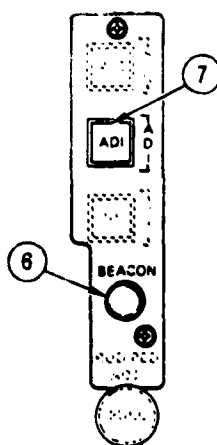


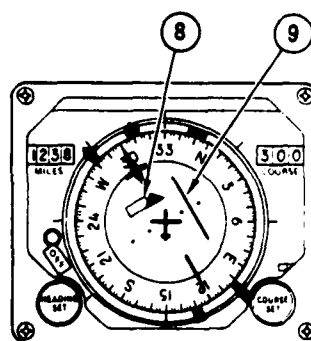
Figure 115 HSI And AI Indicating Devices



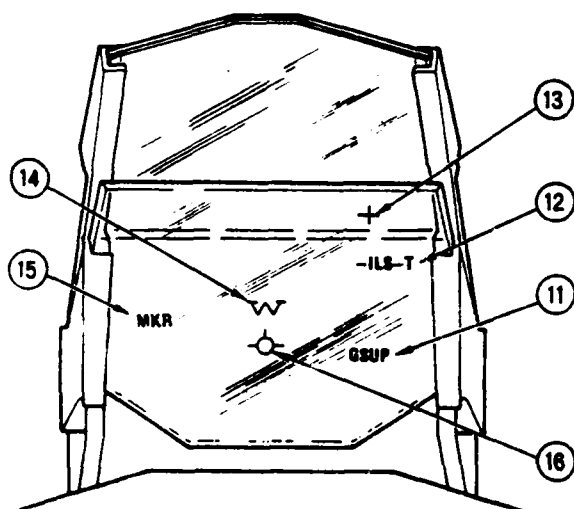
ATTITUDE INDICATOR



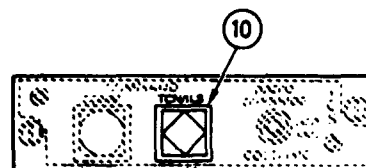
MAIN INSTRUMENT PANEL OR
REAR MAIN INSTRUMENT PANEL



HORIZONTAL SITUATION INDICATOR



HUD DISPLAY UNIT
COMBINING GLASS ASSEMBLY



TAKE COMMAND CONTROL PANEL

LEGEND

1 TF-16A

2 ILS-T INDICATION WITH STEER MODE SWITCH IN ILS/
TCN. ILS-N INDICATION WITH STEER MODE SWITCH IN
ILS/NAV.

3 GSUP INDICATION WITH AIRCRAFT SITUATION BELOW
GLIDE SLOPE. GSON INDICATION WITH AIRCRAFT SIT-
UATION ABOVE GLIDE SLOPE.

1. GLIDESLOPE WARNING FLAG
2. GLIDESLOPE INDICATOR
3. HORIZONTAL POINTER
4. VERTICAL POINTER ALARM FLAG
5. VERTICAL POINTER
6. BEACON LIGHT ASSEMBLY
7. ADI MODE SWITCH
8. HSI COURSE DEVIATION WARNING FLAG
9. HSI COURSE DEVIATION BAR
10. TCN/ILS SWITCH
11. GSUP (WINDOW 6)
12. ILS-T (WINDOW 3)
13. INTEGRATED FLIGHT DIRECTOR
14. AIRCRAFT SYMBOL
15. MKR (WINDOW 2)
16. VELOCITY VECTOR

Figure 116 ILS Indicators

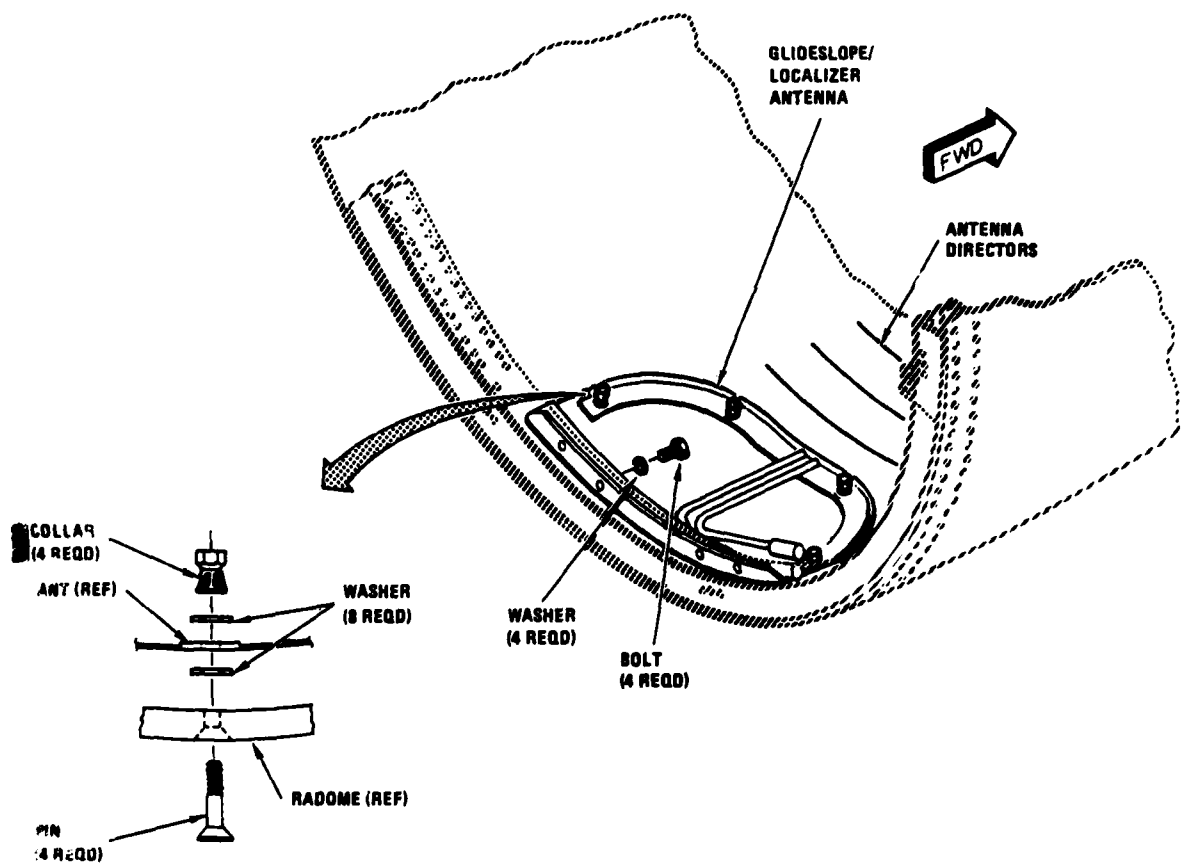
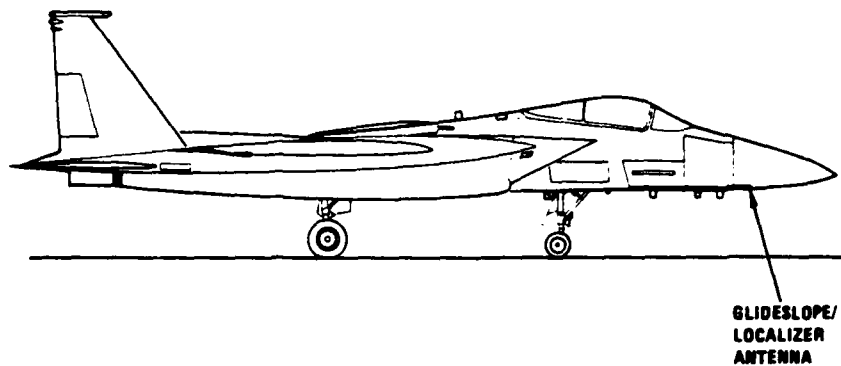
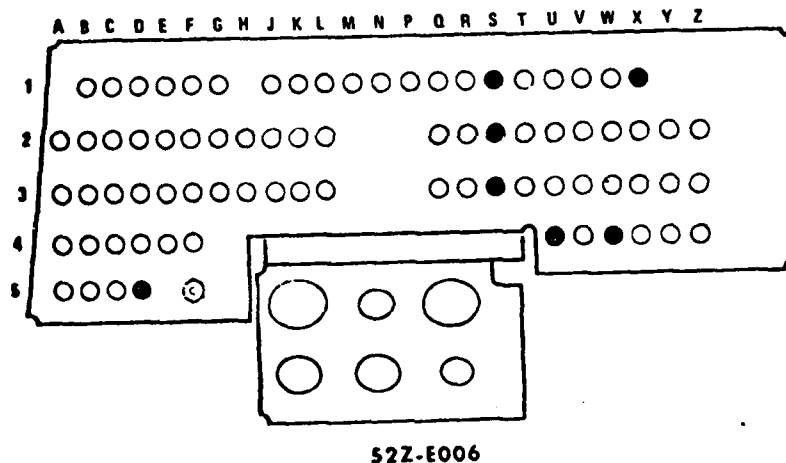
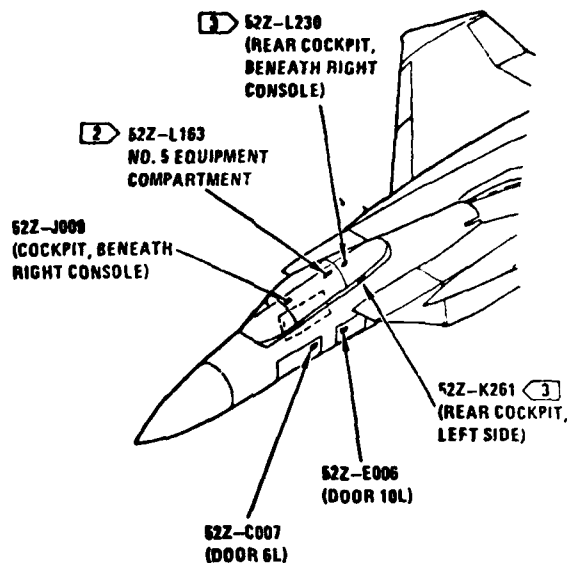


Figure 117 Glideslope/Localizer Antenna Location

LEGEND

1. ONLY SYSTEM AND RELATED SYSTEM CIRCUIT BREAKERS ARE SHOWN. POWER DISTRIBUTION SYSTEM CIRCUIT BREAKERS WHICH SUPPLY POWER TO THE CIRCUIT BREAKERS SHOWN ON THIS ILLUSTRATION ARE SET AS PART OF EXTERNAL ELECTRICAL POWER APPLICATION PROCEDURES. REFER TO T.O. 1F-15A-2-2().

2 F-15A
3 TF-15A



52Z-E006

52Z-E006 LEFT BUS CIRCUIT BREAKER PANEL				
REF DES	ZONE	NOMENCLATURE		BUS
32CB003	X1	INTERIOR LTS	115V ϕ A	L 115VAC ϕ A
54CB011	D5	GND PWR/RUD WRN	28VDC	L 28VDC
74CB003	U4	ILS	28VDC	L 28VDC
80CB004	W4	HUD	28VDC	L 28VDC
90CB007	S1	HUD	115V ϕ A	L 115VAC ϕ A
90CB008	S2	HUD	115V ϕ B	L 115VAC ϕ B
90CB009	S3	HUD	115V ϕ C	L 115VAC ϕ C

Figure 118 Circuit Breakers Location

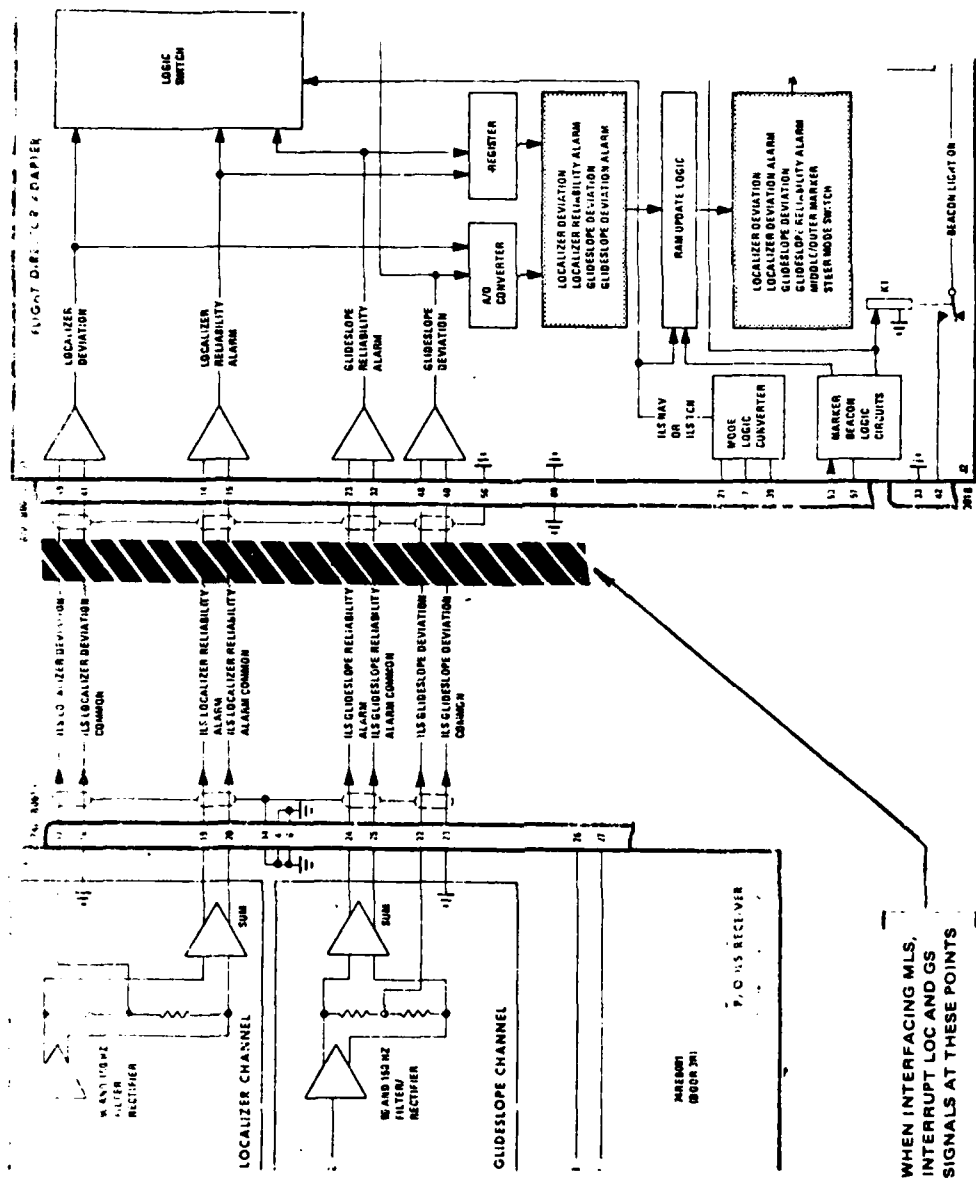
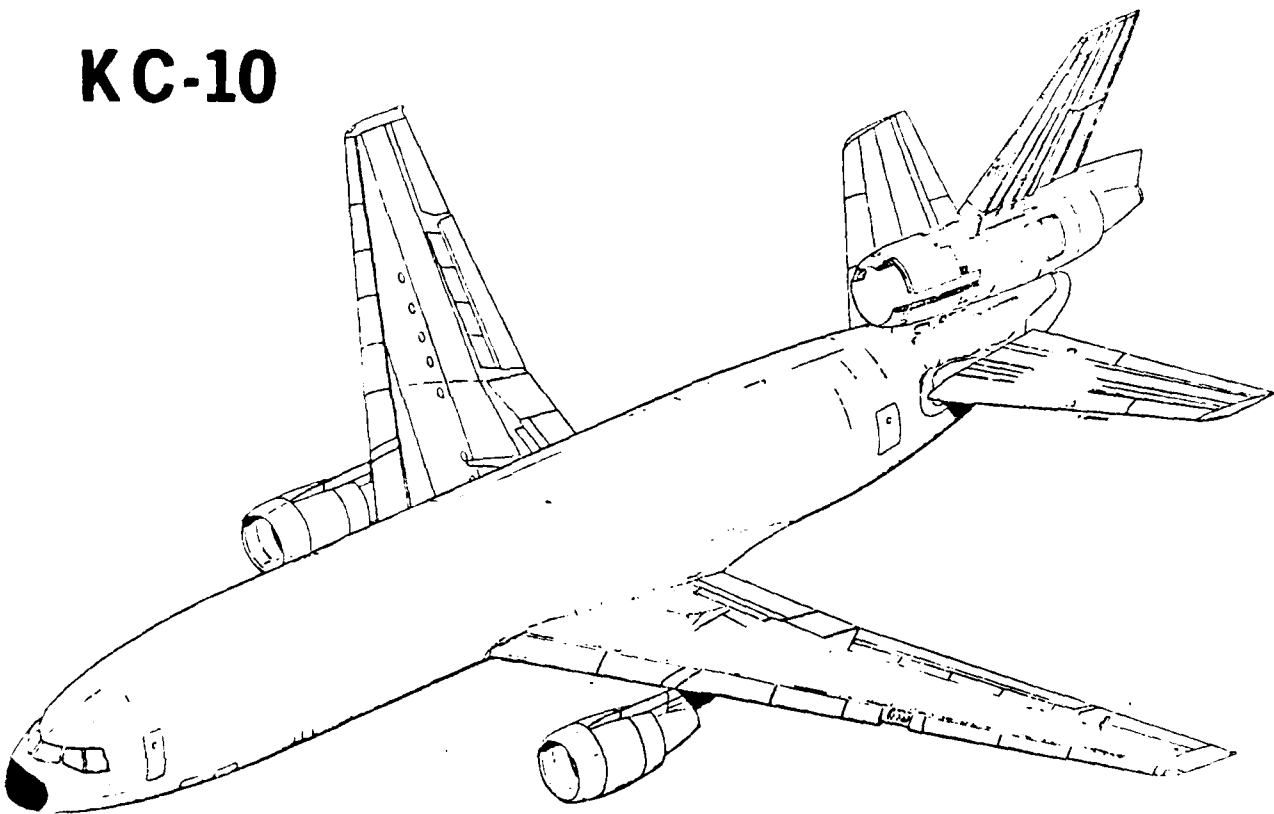


Figure 119 ILS/Flight Director Adapter Interface

MLS CONSIDERATIONS

KC-10



5.6 KC-10A

5.6.1 General KC-10A Information

The McDonnell Douglas KC-10A is a wide-bodied tanker aircraft used for in-flight refueling of all types of aircraft. It is a derivative of the commercial DC-10 Series 30 aircraft.

During this study, the KC-10 avionics had not been finalized and no TO's existed. Information and some preliminary drawings were obtained from McDonnell Douglas, Long Beach, California, and internally from the Flight Systems Division of The Bendix Corporation which designed and manufactured the autopilot/flight director system for both the military and commercial versions of the aircraft. The baseline cockpit arrangement is that of Overseas National Airways (ONA) and the autopilot is a Northwest Orient Airlines (NWA) version. The ONA cockpit was modified to add TACAN and single-cue ADI's.

The MLS-related approach equipment is analog and is certified commercially for Category IIIa fail-operative automatic landings. As such, the landing system is completely redundant, thus making the KC-10A one of the few aircraft in the USAF inventory with Category IIIa capabilities. Because of the autoland avionics presently aboard the aircraft and due to the absence of weight and space restrictions, the KC-10A is an ideal candidate for a MLS-4 complex trajectory configuration if mission requirements warrant.

Integration of the MLS System into the KC-10A aircraft involves consideration of the following existing navigation equipment:

KC-10A NAV EQUIPMENT LIST

<u>DISPLAYS</u>	
<u>QUANTITY</u>	<u>DESCRIPTION</u>
2	Horizontal Situation Indicator (HSI)
2	Attitude Direction Indicator (ADI)
2	Bearing and Directional Heading Indicator (BDHI)
2	Radio Magnetic Indicator (RMI)
2	Radio Altitude Indicator
2	Distance Measuring Equipment (DME)
2	Flight Mode Annunciator (FMA)
3	INS Control and Display Unit (INS-CDU)

KC-10 NAV EQUIPMENT LIST (Continued)

CONTROLS

<u>QUANTITY</u>	<u>DESCRIPTION</u>
2	ILS/VOR Frequency Selector
2	Preset Course Selector
2	Preset HDG Selector
2	TACAN Frequency Selector
2	ADF Frequency Selector
3	INS Waypoint Selector (INS-CDU)

SWITCHING UNITS

<u>QUANTITY</u>	<u>DESCRIPTION</u>
1	Attitude Monitoring and Switching Unit (AMSU)
1	Azimuth Switching Unit (ASU)
1	Radio/INS Switching Unit
1	INS Switching Unit
1	VOR/ILS/TACAN Switching Unit

RECEIVERS

<u>QUANTITY</u>	<u>DESCRIPTION</u>
2	ILS
2	TACAN
2	VOR
2	ADF
2	DME
2	Radio ALT

The following pertinent factors regarding the present aircraft systems must be considered in implementing MLS in this aircraft:

- The basic DC-10 system philosophy is duplication of all displays, controls, sensors, receivers, etc. (No. 1 and No. 2 systems).
- The Inertial Navigation System (INS) is triplicated. Attitude information is supplied by the platforms. The third INS system (No. 3 or AUX) is standby and can be substituted for either the No. 1 or No. 2

system. Three INS control and display units are included and provide independent or common waypoint selection for the three computers. INS is capable of accepting information from an automatic data entry unit, however, interfacing provisions have not been included in the aircraft.

- Two separate, identical, autopilot/flight director (AP/FD) systems are installed and each drives separate control surfaces in each axis to provide a high level of availability and the required redundancy for a Category IIIa certification.
- A flight guidance control panel mounted in the center of the glare shield provides the means to engage the autopilot, autothrottle, and flight director systems. Single pushbuttons are provided for each mode and both systems are engaged in the same mode when the pushbuttons are activated.
- Flight mode annunciators (FMA), mounted above each ADI, contain four windows for displaying the various modes of the autothrottle and AP/FD systems. These windows display in left to right order: autothrottle modes; AP/FD arm modes; AP/FD roll modes; and AP/FD pitch modes. Each window is capable of displaying 32 separate legends of up to 8 characters (e.g., LOC TRK, GS TRK, DUAL LAND, MLS TRK).
- Operation in the automatic landing consists of the following events in the following mode sequence:
 1. First autopilot engaged
 2. Land mode armed
 3. Second autopilot armed
 4. Localizer and glide slope beams captured and now being cracked
 5. Preland test initiated
 6. Preland test completed after forty seconds
 7. Second autopilot coupled to surfaces and "DUAL, LAND" mode annunciated
 8. Align mode engages at 137 ft
 9. Flare mode engages at 50 ft
 10. Ground rollout mode engaged when aircraft touches down

- The present DC-10 autoland control laws and logic operation have been designed around normal ILS approach procedures. To avoid changes in these areas: final approach glide slopes must be between 2.5° and 3.0° ; the localizer and glide slope modes must be inhibited until a final approach is established; and, final approach lengths must be greater than 4 nm or else the preland test completion altitude detector must be decreased below its present 500 ft. level.

Block diagrams of the MLS-related interfaces are illustrated in Figures 120, 121 and 122. Identification numbers have been assigned to the various elements. Table 10 lists the equipment, its location, and associated Figure number. The cockpit is illustrated in Figures 123 through 126.

Figure 120 illustrates the NAV/ILS/HSI interface. Lateral deviation information from the various horizontal references can be selected for display on the HSI via two switches, RAD/INS and VOR/ILS/TAC, mounted on the NAV module of the flight guidance control panel (see Figure 125). The RAD/INS switch is used to select either the INS or one of the radio (RAD) references for display. In the RAD position, the selected reference is a function of the VOR/ILS/TAC switch position. In the TAC position, the TACAN reference is displayed and in the VOR/ILS position (dependent on the frequency selected), either the ILS or VOR reference is displayed. Frequency discrimination is a function of switches internal to the ILS tuning mechanism.

Solid circles on Figure 120 show the functions interrupted and routed through the MLS switching unit when MLS is installed.

The NAV/ILS/AP-FD/ADI interface is illustrated in Figure 121. If an ILS frequency is tuned and either the ILS or land mode is selected (see Figure 125) via the control panel pushbuttons, switching internal to the autopilot/flight director (AP/FD) computers selects the ILS deviations for flight path control computations. The AP/FD computer provides the servo drive and flight director steering commands. Solid circles on Figure 121 show the functions interrupted and routed through the MLS switching unit when MLS is installed.

Figure 122 illustrates the course select and DME interface. The course and heading references presented to the HSI are a function of the position of the RAD/INS switch. In the INS position, the INS system provides references and in the

RAD position, the AP/FD control panel provides references. A common actuator on the NAV module of the control panel is used to provide the course select, reference for the AP/FD, TACAN, and VOR receivers. These receivers in turn generate bearing information for the BDHI and RMI (pointer No. 2). The TACAN receiver generates distance information which is displayed on the DME indicator.

Solid circles on Figure 122 show the functions interrupted and routed through the MLS switching unit when MLS is installed.

5.6.2 KC-10A MLS Recommendations

Since the existing KC-10A has Category IIIa capabilities and will operate at fixed air bases with full coverage MLS capability, an MLS-4 complex trajectory configuration is recommended if mission requirements warrant. Workload problems associated with complex trajectory flight should not be serious since the aircraft has a three-man cockpit. Display capability is only a problem if the proposed electro-mechanical instrumentation is found to be insufficient for complex trajectory flight.

Installation of an MLS-4 system in the KC-10 type aircraft involves the addition of the following:

<u>UNIT</u>	<u>QUANTITY</u>
MLS Angle Receiver	2
MLS Angle Antenna	4
DME Interrogator	2
DME Antenna	4
MLS Control/Display Unit	2
MLS NAV (Complex Trajectory) Computer	2
MLS AD/DME Display	2
MLS/ILS Switch	2
MLS/ILS Switching Unit	2
MLS/VOR RMI Switch	2

Space is not a problem on the KC-10A aircraft and all of the units can be accommodated. Ample electrical power is available and MLS circuit breakers can be easily added to the existing panels.

MLS CDU's are the only large units required to be added to the cockpit and a suggested rearrangement of the forward pedestal panels is illustrated in Figure 127. As an alternate, it may be possible to include the MLS computations in the INS system and utilize the existing INS CDU's (Item 18, Figure 156) for trajectory selection. Further study of this alternate is beyond the scope of this investigation and should be considered for the final retrofit definition.

MLS/ILS and MLS/VOR RMI switches are added to the instrument panels and are illustrated on Figures 123 and 124 (Items 19 and 21, respectively).

The MLS will utilize the number 2 pointers of the existing RMI's to display bearing-to-station when the MLS/VOR RMI switch is placed in the MLS position. In addition MLS will utilize the present INS DME indicator on the HSI to display along track distance to the GPIIP when an MLS complex trajectory approach is being flown.

The MLS AZ/DME displays are added in the space provisions for the performance and failure assessment monitor display which is utilized by several commercial airlines.

In order to accommodate the MLS-4 configuration, the pitch and roll computers of the autopilot must be modified to accept the pitch and roll complex trajectory steering signals from the MLS computer. In addition, the present modal logic must be modified to provide the appropriate control law switching automatically.

MLS selection will be annunciated by the position of the MLS/ILS switch and an MLS light mounted in some convenient location on the instrument panel. The various phases of the MLS control will be annunciated by the existing approach annunciations; (i.e., ILS arm, land arm, LOC capture and track, and glide slope capture and track). As an alternative, MLS flight can be annunciated specifically on the flight mode annunciators by appropriate modification to the FMA tapes and pitch and roll computers such that MLS legends appear (i.e., MLS arm, AZ capture and track, and EL capture and track).

MLS Operation

The sequence of operation and events related to an MLS complex trajectory flight using the proposed controls is as follows:

- 1) Define trajectory to MLS computer using MLS Control Display Units (both pilot and co-pilot).
- 2) Place RAD/INS switches on flight guidance control panel to "RAD" position and VOR/ILS/TAC switches to "VOR/ILS" position.
- 3) Place INS/ILS switches on instrument panel to "MLS" position and MLS/VOR RMI switch to "MLS" position and VOR/AFD-2 switch on RMIs to VOR position.
- 4) Select INS channel on MLS CDUs.
- 5) As a result of the above procedure, MLS information is displayed on the following indicators:

Indicator

References

HSI	Lateral deviation, flag, along track distance, desired track angle, path anticipator.
ADI	Vertical deviation, flag, steering.
RMI (Pointer 2)	MLS station bearing.

Azimuth and range to the GPIP will be displayed on the MLS AZ/DME indicators as soon as the MLS channel is tuned. It may be useful to interlock the power to this display through the MLS/ILS switch if the FMA is not modified with MLS legends. In this manner, the absence of azimuth and DME indications will indicate a procedural error.

- 6) Select ILS or land mode via pushbutton on flight guidance control panel. This action arms the MLS system.
- 7) Automatic engagement of the MLS trajectory will occur when the capture logic in the MLS computer is satisfied. When the final approach segments are engaged, the MLS system will switch from computed path references to raw data control in azimuth and elevation.

TABLE 10
Equipment Identification and Location

ITEM NO.	TITLE	LOCATION	
		PHYSICAL	FIGURE NO.
1	ILS RECEIVER	MAIN RADIO RACK	-
2	VOR RECIEVER	MAIN RADIO RACK	-
3	TACAN RECEIVER	MAIN RADIO RACK	-
4	INS	NAVIGATION RACK	-
5	VOR/ILS/TACAN SWITCH	CONTRL PANEL	154
6	VOR/ILS/TACAN SWITCHING UNIT	MAIN RADIO RACK	-
7	RAD/INS SWITCH	CONTROL PANEL	154
8	RAD/INS SWITCHING UNIT	MAIN RADIO RACK	-
9	HSI	INSTRUMENT PANEL	152 153
10	AUTOPILOT/FLIGHT DIRECTOR COMPUTERS	MAIN RADIO RACK	-
11	AUTOPILOT SERVOS	WINGS AND TAIL	-
12	FLIGHT DIRECTOR CMD SWITCH	OVERHEAD PANEL	155
13	ADI	INSTRUMENT PANEL	152 153
14	NAV MODULE	CONTROL PANEL	154
15	DME INDICATOR	INSTRUMENT PANEL	152 153
16	BEARING/DISTANCE/ HDG INDICATOR	INSTRUMENT PANEL	152 153
17	RMI	INSTRUMENT PANEL	152 153
18	INS CONTROL DISPLAY UNIT	FORWARD PEDESTAL	156
19	MLS/VOR RMI SWITCH	INSTRUMENT PANEL	152 153
21	MLS/ILS SWITCH	INSTRUMENT PANEL	152 153
22	MLS AZ/DME DISPLAY	INSTRUMENT PANEL	152 153

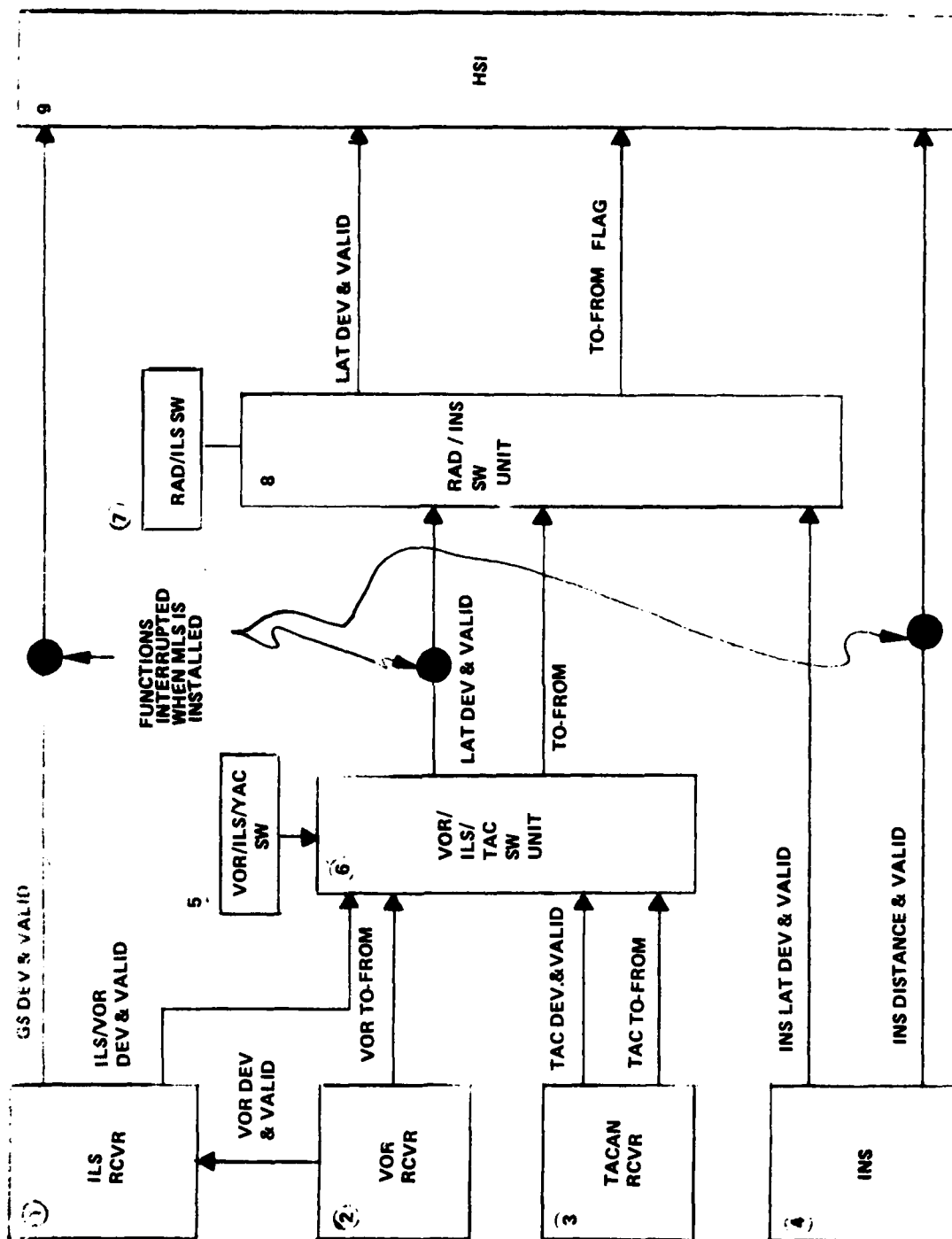


Figure 120 NAV/ILS/HSI Interface

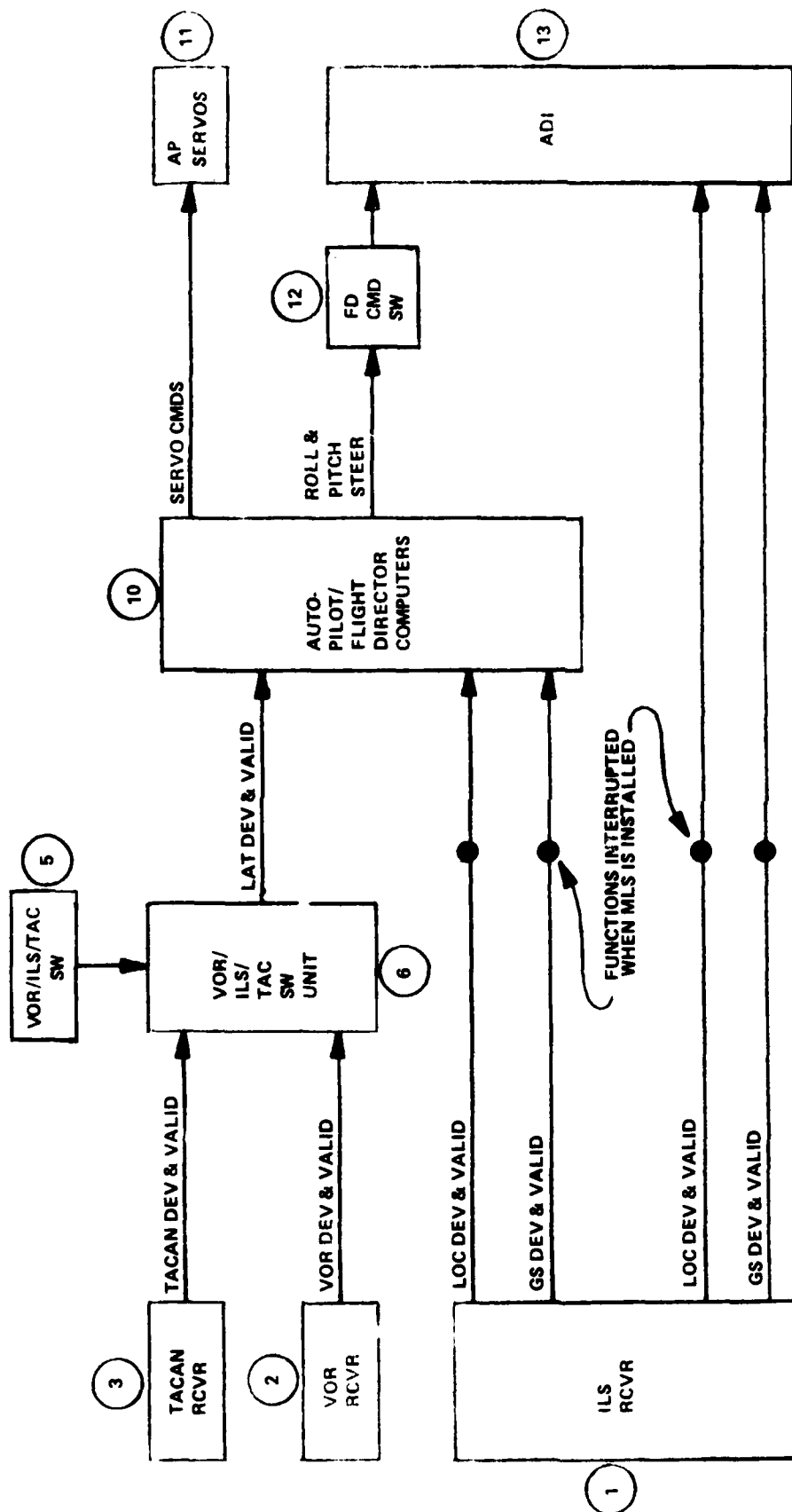


Figure 121 NAV/ILS/AP - FD/ADI Interface

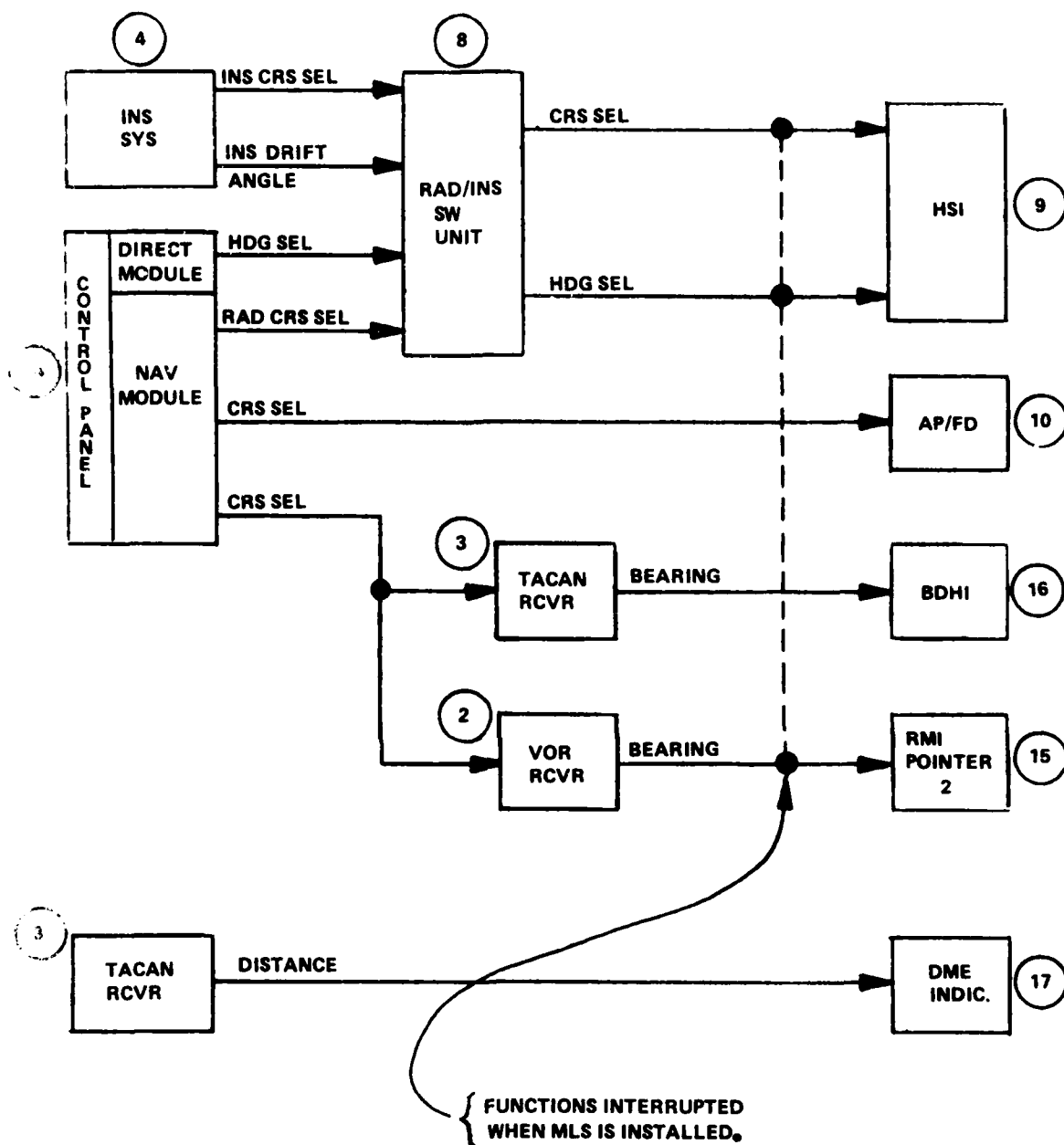


Figure 122 Course Select And DME Interface

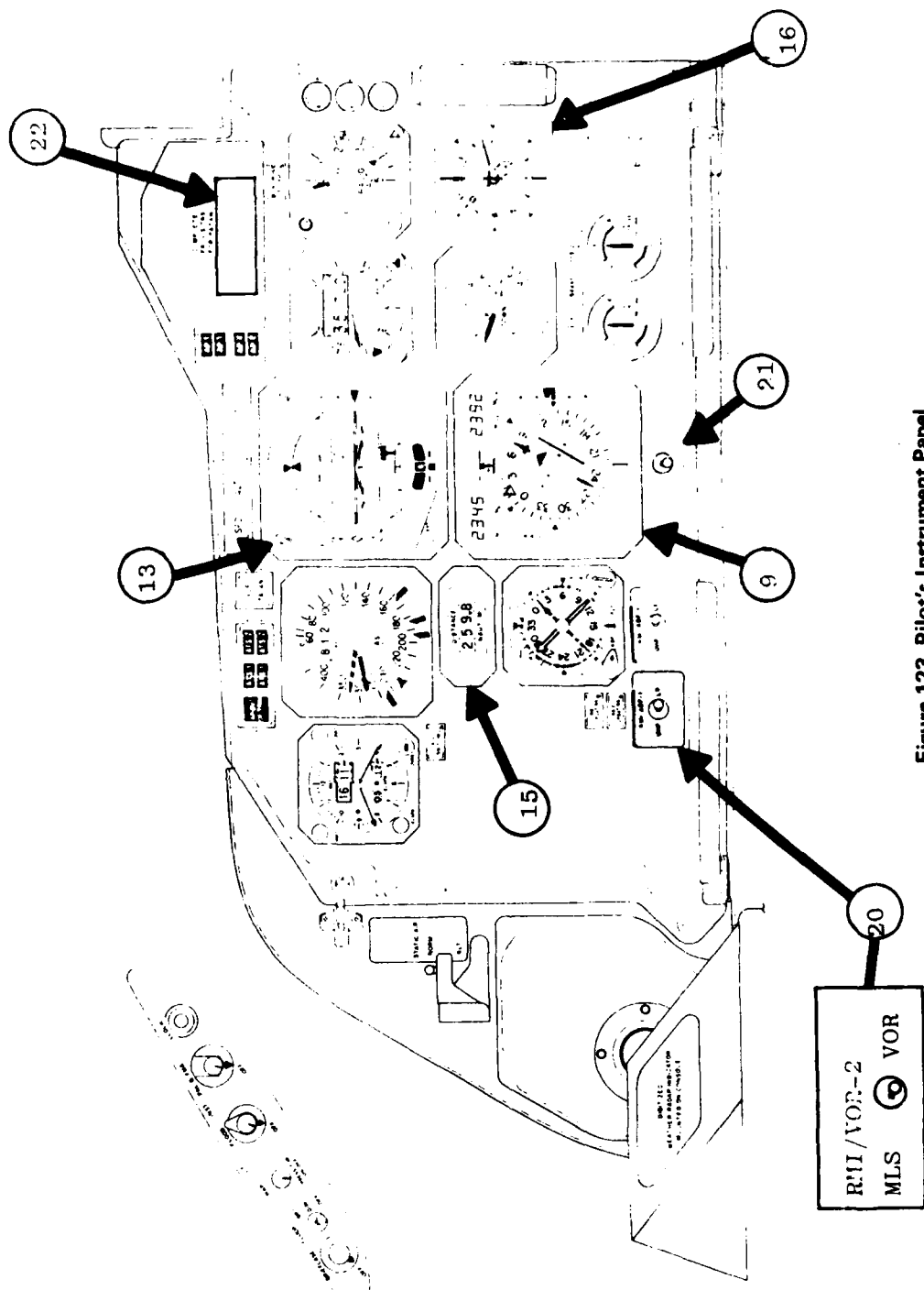


Figure 123 Pilot's Instrument Panel

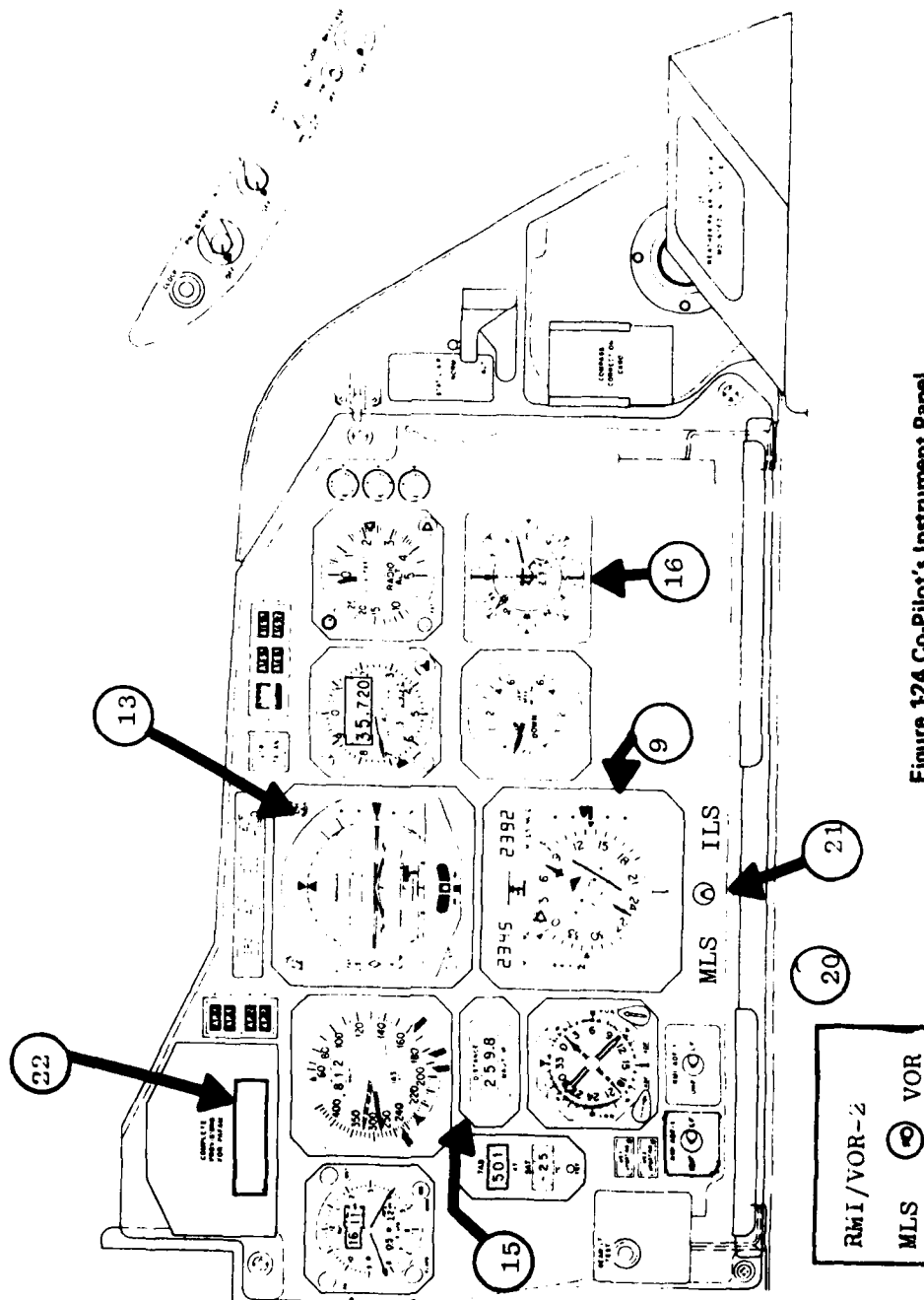


Figure 124 Co-Pilot's Instrument Panel

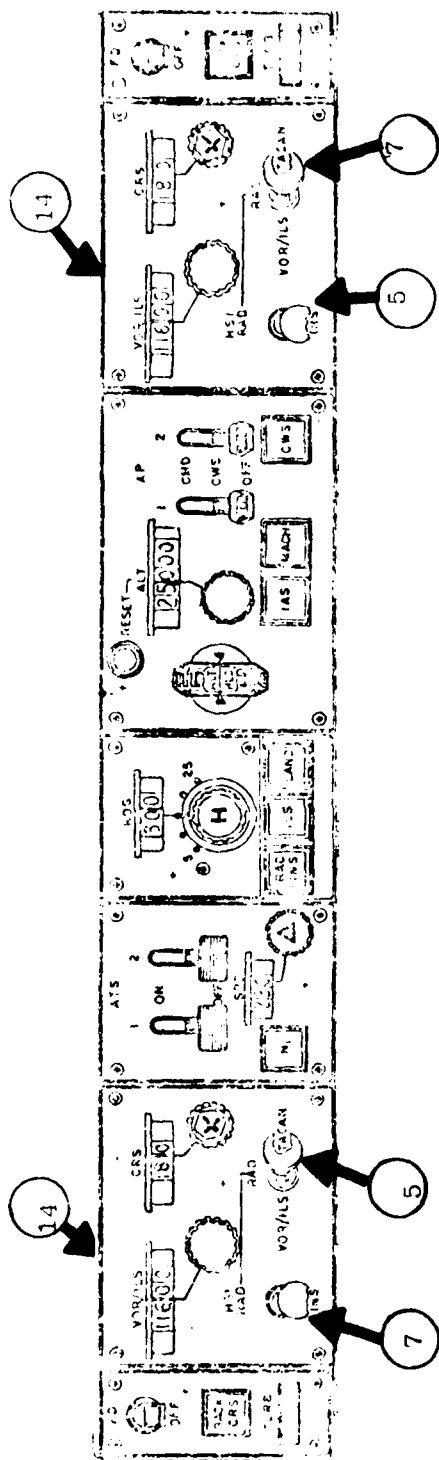


Figure 125 Flight Guidance Control Panel And Center Instrument Panel

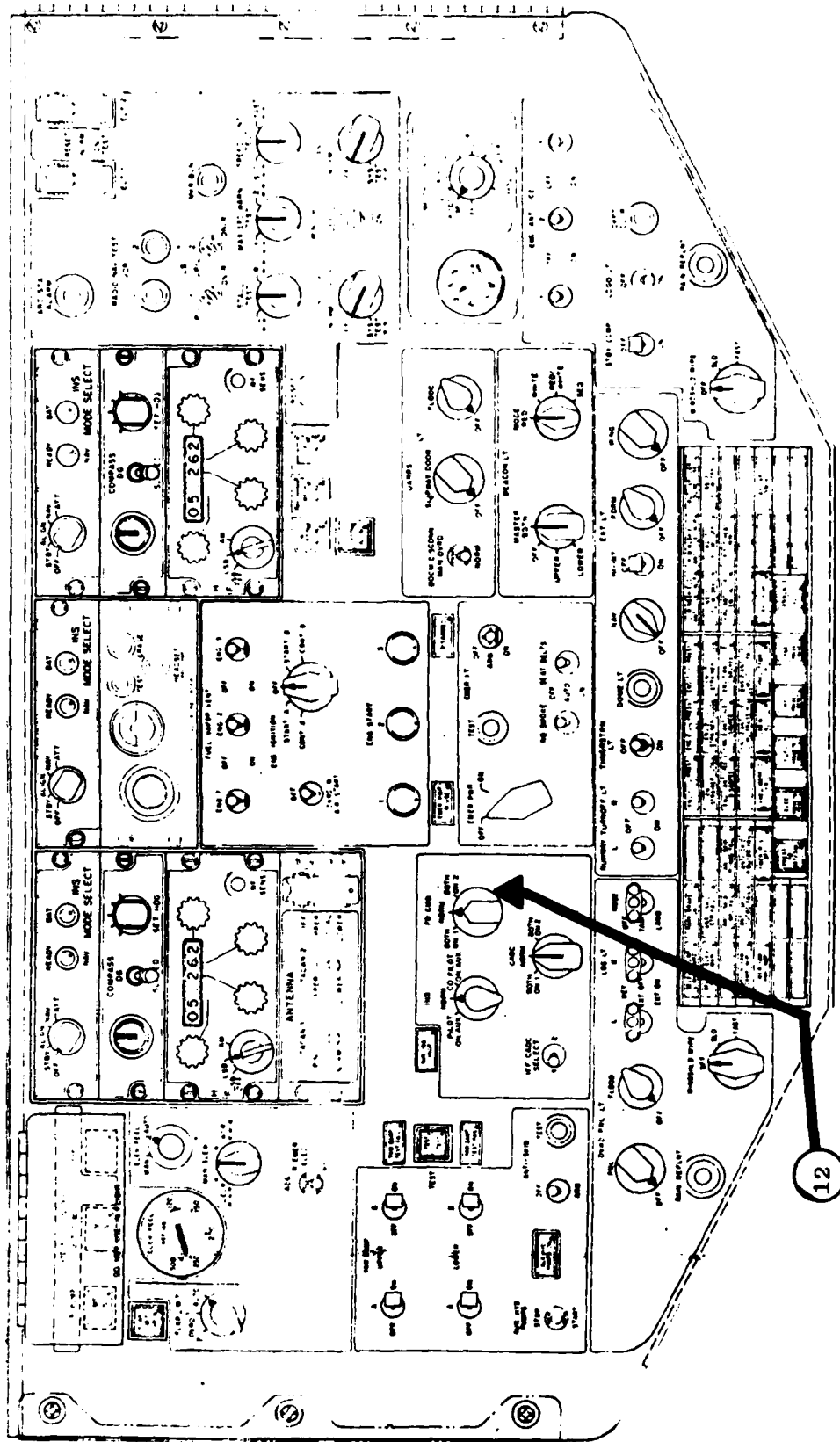
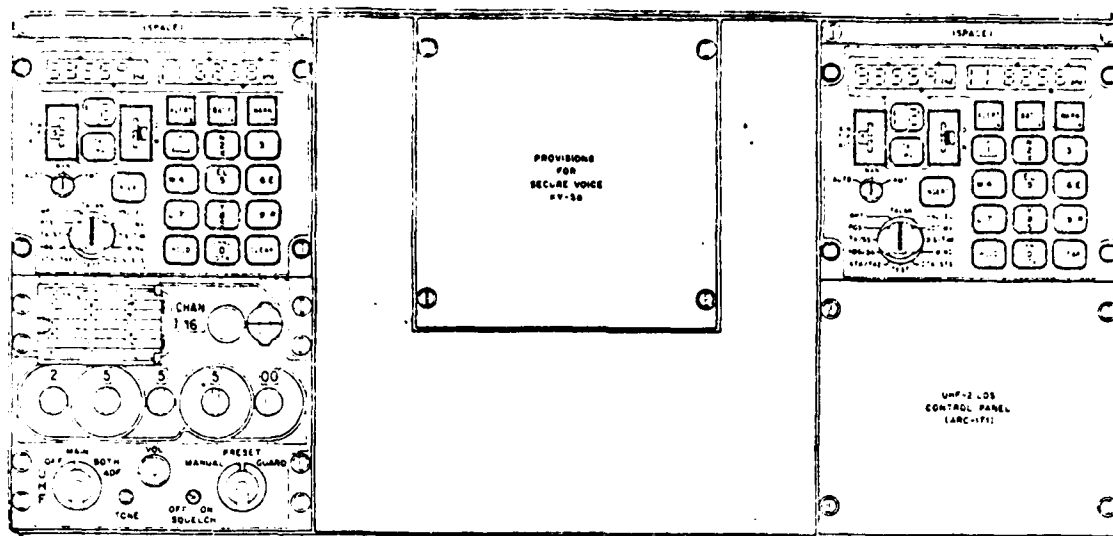
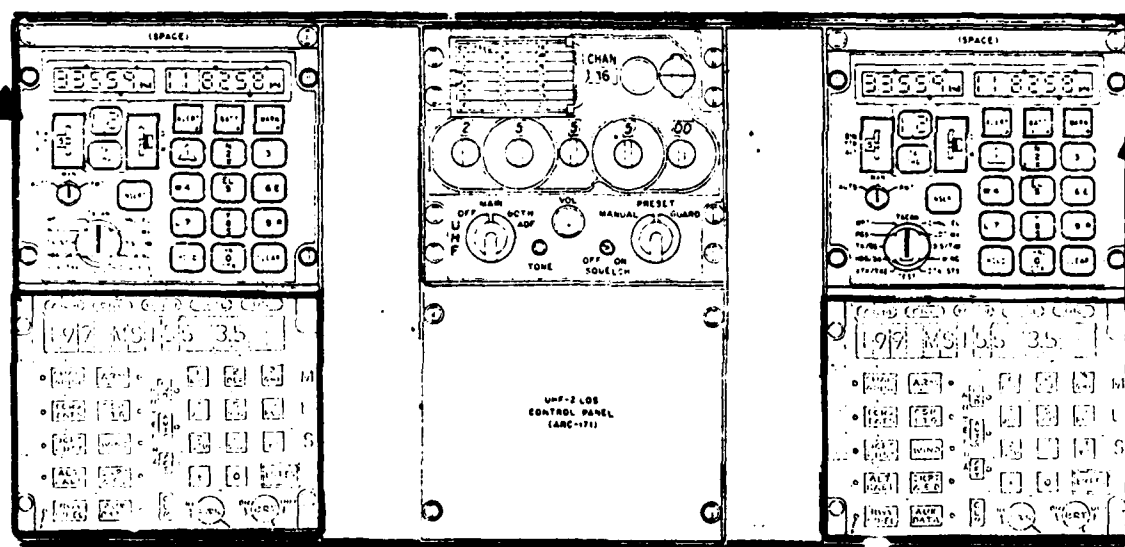


Figure 126 Overhead Panel



PRESENT



MLS MODIFIED

Figure 127 Forward Pedestal

6.0 DESIGN DEFINITION PHASE ACTIVITIES

6.1 Overall Use of the Cockpit Simulation

The fixed-base cockpit simulator, developed for use in this program, provides a means for:

- Design Concept Refinement
- Formal Design Tradeoff Studies
- Design Evaluation
- System Demonstration

Each of these functions is discussed in terms of its major characteristics and its appropriate procedures in the following paragraphs.

6.1.1 Design Concept Refinement

The simplest use of the simulator is that in which the device serves as a tool to aid design engineering in narrowing down the number of possible control-and-display alternatives. This is particularly true for electronic CRT display development due to the programmable nature of this equipment.

In the typical environment, provided by the cockpit simulator, the displays are rendered in the true colors, sizes and surroundings of the proposed hardware. Most importantly, the display elements move in a closed-loop, real time fashion which is representative of actual use.

The simulator can reveal to the designers some advantages and some limitations which could not be seen in static drawings. Sometimes it will be seen that things which move together reduce perceptual clutter because they tend to be seen as one moving object. Sometimes things in relative motion do not interfere visually with each other because they are perceived as lying in different planes. Sometimes it will be seen that elements do interfere with each other during motion by masking, causing distortion, or misleading the pilot.

In this use of the simulator, the persons who are observing the displays are those who make conceptual drawings and otherwise engage in design development. They either fly the simulator themselves or have someone fly it for them while they concentrate on observing the displays. When an experienced pilot flies the

system, the purpose should be to obtain suggestions about the appropriateness of the design features. Neither the aim nor the questions should address the issue of how well the display serves the function, since that issue requires more sophistication in measurement.

6.1.2 Formal Design Tradeoff Studies

After the designs have been narrowed down to a set which represent viable alternatives, formal design tradeoff studies are begun. It is the purpose of the trade study to assign relative figures of merit to each of the candidate designs, and to help select the major contenders. It is important that the candidates represent a range of design alternatives.

The questions to be answered in the design trade study are no longer about design features as in the case of the earlier procedure. The questions now are of the form, "Is pilot performance better with A, or B, or C?" The simulation procedures will answer questions like this and the effects of specific design features can only be inferred from the relative figures of merit.

The design tradeoff study involves the measurement of performance of pilots making landing approaches using the MLS control/display equipment. Enough care needs to be exercised in the selection of pilot subjects, in the simulation of the task, and in the measurement of performance to allow a prediction that the order of merit of the displays in this simulation would be the same as it would be if they were in production and in regular use.

In the design tradeoff studies, performance should be measured only for runs by experienced instrument pilots, who know what it feels like to be groping for the ground by means of electronic aids while managing a fast-moving aircraft that cannot be slowed down in the air and cannot be held up very long. The critical issues for the MLS controls and displays are the way in which they fit into that perceptual habit structure.

6.1.3 Design Evaluation and Validation

The third major category of uses for the simulator is that of design evaluation. The kind of question to be answered by this procedure is whether the MLS landing can be done well with the refined control/display system and whether it can be done well

enough to warrant the expenditures for procurement of the new hardware.

The logic of this procedure suggests that two sets of controls and displays should be included in this evaluation and validation experiment:

- A minimum modification of ILS controls and displays, reworked to be driven by the MLS electronics, which provide a limited complex trajectory capability as designated by the MLS-3 System discussed in Section 4.1.
- The set of specially designed controls and displays (including the electronic CRT) which are proposed to take full advantage of the MLS in future aircraft.

This evaluation and validation procedure should be done by measuring the performance of instrument-qualified pilots flying simulated approaches of various types with regard to varying types of local area conditions.

6.1.4 System Demonstration

The fourth category of use for the simulation of the pilot's task using the MLS controls and displays is that of system demonstration. This use involves the communication of technical data to decision makers. It assumes that the engineering and scientific data produced in the technical development procedures do not sell themselves. The critical technical data needs to be illuminated by some additional activities and put into a form in which many participants will be given an understanding of the results of the technical development program. A complex system such as MLS can profit greatly from demonstrations in which the displays are in motion in a real life environment.

6.2 Specific Simulator Activities in Design Definition Phase

This section discusses some of the specific issues associated with the candidate control-and-display configurations, which require further evaluation and concept refinement in the cockpit simulator. These issues include:

- The incorporation of the MLS-3 configuration to provide an austere complex trajectory capability on a retrofit basis
- The candidate CDU and check-point design methodologies affect on pilot workload
- The relative merits of the 2-D and 3-D electronic CRT display formats
- The relative merits of the improved electro-mechanical display format
- The use of the approach plates in conjunction with monitoring

A brief description of the questions associated with these issues follows.

6.2.1 Incorporation of MLS-3 Configurations

In the USAF FPI Program, serious doubt was expressed regarding the use of present-day electromechanical control-and-display instrumentation for complex trajectory flight. This was based on high pilot workload levels associated with data entry, and orientation problems while tracking the curved path multi-segmented approaches.

In this study the MLS-3 configuration was developed to reduce these problems to a minimum by constraining the complexity of the trajectory to a maximum of two segments. It results in a simplified data entry scheme and orientation problems no worse than those involved with the approach to intercept the ILS localizer.

The cockpit simulator will be used to observe pilot workload and operation with this system and to answer the following questions:

- Are pilot workload levels acceptable for data entry?
- Is orientation a problem with the electromechanical display information?
- Can these simplified complex trajectories be done safely in single-seat aircraft with flight director guidance?

- Can failures be detected and can missed approaches be executed safely?

6.2.2 Effect on Pilot Workload of Candidate CDU

Software and hardware modifications can be made, in conjunction with the T-39 CDU and digital computer, to simulate one of the proposed candidate CDU configurations. This would also require modifications to the trajectory definition software and the generation of new algorithms to implement the automatic test capability associated with the "check-point." The object of the simulator activity will be to determine if pilot workload is reduced to acceptable levels (by reducing the number of data entries and by eliminating the need for an extensive pilot-conducted test) to obviate the need for automatic data entry.

6.2.3 Relative Merits of 2-D and 3-D Electronic Display Formats

The 2-D and the 3-D displays differ markedly in the way they encode certain parts of the pilot's control information. For purposes of situation planning, the 2-D format shows distance as the vertical dimension of the display. In the 3-D display that distance is shown through an illusion of depth created by the perspective lines.

It is probably true that the 2-D display will do better in providing a view of the situation for planning. The 3-D may provide some advantage in performing the attitude control task. The simulator will be used to compare these concepts and evaluate each against the task requirements of pilots in the terminal area.

The following paragraphs discuss how the simulator will be used to evaluate some of the display elements of the 2-D and 3-D formats.

6.2.3.1 Perceptual Separation of Display Features

It has been observed in previous projects that head-up displays are less interpretable as static pictures than when they are in motion in use. It is similarly expected that this will occur with both the 2-D and 3-D displays. There are a number of display elements to be discriminated and interpreted. Color has been used in these displays to help separate families of display elements. The simulator animation will help considerably in verifying and evaluating the extent to which the designs are perceived as predicted in the analysis.

6.2.3.2 The Systematic Use of Display Color Assignment

Elsewhere in this report it has been stated that color in the displays has been used systematically to help in the pilot's interpretation of the displays. In some cases, all three colors are utilized in the same display space. The simulator will be highly useful in determining the extent to which the color assignments aid and do accomplish the design objectives. The color assignments can be varied easily to provide experimental aids to analysis.

6.2.3.3 Interpretability of Attitude Pitch Lines

Because of the number of elements in these complex displays, the number of pitch lines shown for attitude reference has been held to a minimum. The analysis for this design suggests that two or three lines are adequate.

The ability to suppress lines and put on only those needed is one of the things which is possible with electronic attitude displays. This also means that there is not much actual behavioral experience behind the performance prediction. It seems necessary to produce data in the simulator which will verify this concept or cause it to be changed.

6.2.3.4 Habit Interference in Reading the Bank Scale

The top portion of both the 2-D and 3-D displays is used as the primary heading or track compass. That information is there for what is judged to be very important display system reasons. But that same space can consequently not be used very well for a scale of bank angle. Therefore, the bank angle display has been located on the bottom center of the display.

Though its color is different from that of the compass display and the curvature of the scale different, it is possible that this scale may sometimes be interpreted to be the reciprocal of heading. The simulator will be used to help assess the extent to which this possible interference actually occurs.

6.2.3.5 Variable Scale Factors in the Situation Display

Elsewhere in this report it has been noted that the electronic display medium now makes it relatively easy to change the scale factor in displays. It seems quite likely that some important benefits to performance can be obtained by so doing.

It has been noted that the visual angle in reading a 4-inch compass scale is only 1/10 of that in an out-the-window display of direction in the world. This suggests that the ability to read heading may be enhanced by magnifying the scale by a factor of 10 when fine control is desired. It has also been suggested in this report that the area for situation display should in some cases use the whole space to depict two miles and at other times 20 miles.

The simulator will be used to explore the range of useful scale factors and whether scale changes should be continuous or discrete.

6.2.3.6 The Interpretability of Flight Path Angle

At the reference point for reading altitude there are two displays of flight path angle. Air-defined or ground defined flight path angle is closest to the altimeter scale depending on the mode of flight. This angle is the vector sum of true airspeed (or ground speed) and vertical speed. It is very useful when descending on a segment which does not terminate on the GPIIP. To the left of the actual flight path angle is a display of the commanded flight path angle. This display element originates from the triangle marking vertical deviation from the commanded flight path. One reason for displaying these parameters in this relationship is that an asymptotic approach to the vertical commanded path can be made by aligning the bottoms of the two FPA indicators.

The utility of these displays will be further evaluated in the simulator.

6.2.3.7 The Legibility of the Associated Displays of Pitch Attitude and Flight Path Angle

One of the ways in which the advantages of the electronic display media have been exploited is in the display of both pitch attitude and flight path angle on the attitude indicator.

There is only one calibrated scale for pitch. The reference for the aircraft has been doubled in order to produce a display of both angles. That reference which is constant and at the center of the display is used for reading the flight path angle. The second aircraft reference symbol rises out of the fixed reference, as angle of attack increases, to show the pitch attitude angle. It is this reference line which grows humps to display flight director pitch rate commands.

The legibility of these symbols will be evaluated in the simulator.

6.2.4 Relative Merits of Improved Electromechanical Display Format

The proposed improvements to the electromechanical display presentation of the T-39 (i.e., path anticipator on HSI and combined azimuth/DME display) should be evaluated in the simulator to determine if the total information presented provides the pilot with adequate orientation capability for the general complex trajectory. Improving this electromechanical display information to the point of adequacy shall continue to be a goal of the simulation phase since it will open the door of complex trajectory flight to a large number of existing aircraft.

This evaluation must consider autopilot vs. flight director approaches, failure detection, and missed approach execution.

6.2.5 Approach Plate Formats

One of the topics addressed in this study was approach plate design. Several different schemes were presented: the T-39 type with a map view and a profile view; 3-D perspective; and 3-D pseudo-perspective. These presentations could be a subject for evaluation in the simulator.

APPENDIX A

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APPENDIX B

ANALYSIS OF THE ROLE OF A PREDICTOR IN A HORIZONTAL SITUATION DISPLAY

B.1 General

An Electronic Horizontal Situation Display, showing the position of the aircraft relative to the desired trajectory, is anticipated to be one of the candidate displays for Phase II evaluation. The literature indicates that the addition of a predictor to such a display greatly improves the ease with which the pilot can capture and track the trajectory.

The purpose of this analysis is to obtain some analytical insight into the role of the predictor in the capture and tracking task by equating it to other known control/display mechanisms, and in particular to attempt to analytically determine the optimum predictor length.

B.2 Predictor Equations

Figure B-1 illustrates a horizontal map situation at a particular instant when the aircraft is to the right of, and flying away from the desired track. The predictor indication is shown emanating from the aircraft symbol initially in the direction of the aircraft's present track and forming a circular arc of length VT . V is the aircraft's ground velocity and T is the desired prediction time.

The aircraft position error is designated as y . The difference between the desired and present track angles is designated the Track Angle Error (TAE). R is the radius of the predictor arc and A is the enclosed angle.

The distance d represents the displacement of the end of the predictor from the desired track (measured perpendicular to the track). It is desired to solve for d in terms of y .

From the geometry one obtains:

$$d = y + 2R \sin \frac{A}{2} \sin \left(\frac{A}{2} + \text{TAE} \right) \quad (\text{B-1})$$

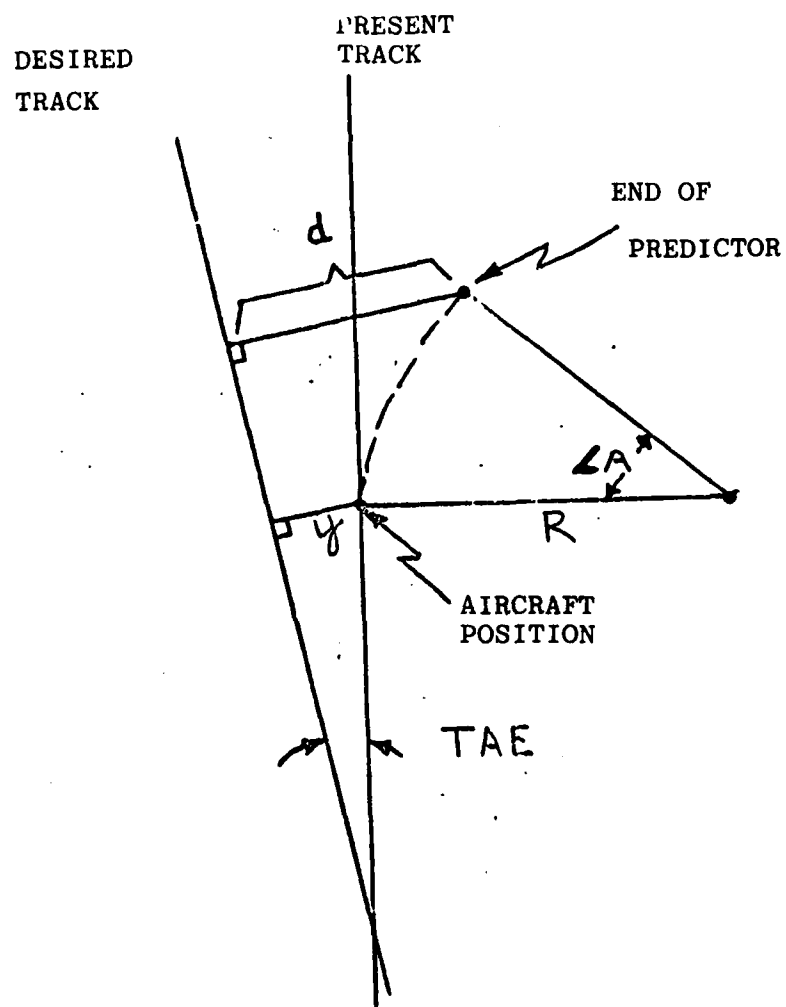


Figure B-1 Horizontal Situation Display With Predictor

Expanding:

$$d = y + 2R \sin \frac{A}{2} \sin \frac{A}{2} \cos TAE + \cos \frac{A}{2} \sin TAE \quad (B-2)$$

This equation may be linearized by first assuming that the aircraft maneuvers will be restricted to standard turns or less. In a standard turn the radius of turn R is given by:

$$R = \frac{V \times 120}{2 \pi} \quad (B-3)$$

The enclosed angle A is equal to the arc length divided by the radius, therefore:

$$\frac{A}{2} = \frac{VT}{2R} = \frac{2\pi \times T \cdot \frac{1}{40}}{2 \times 120} \quad (B-4)$$

Recognizing that we are concerned with predictor times of about 10 seconds, A/2 will be a maximum of .25 rad and the normal small angle assumptions are then valid. Accordingly, we set:

$$\sin \frac{A}{2} = \frac{A}{2} = \frac{VT}{2R} \quad (B-5)$$

$$\cos \frac{A}{2} = 1 \quad (B-6)$$

Substituting 5 and 6 into 2 :

$$d = y + VT \sin TAE + \frac{V^2 T^2}{2R} \cos TAE \quad (B-7)$$

The radius of the predictor arc will be computed for display as:

$$R = \frac{V^2}{\phi g} \quad (B-8)$$

where ϕ is the roll angle of the aircraft.

Now, assuming coordinated turns:

$$g\dot{\phi} = V(\dot{TAE}) \quad (B-9)$$

$$\dot{y} = V \sin (TAE) \quad (B-10)$$

$$\begin{aligned} \ddot{y} &= V (\dot{TAE}) \cos(TAE) \quad (V = \text{constant}) \quad (B-11) \\ &= g\dot{\phi} \cos (TAE) \end{aligned}$$

Substituting equations 8 through 11 into equation 7 we obtain:

$$d = y \frac{T^2}{2} + yT + y \quad (B-12)$$

This is the desired linear differential equation relating the displacement of the end of the predictor (from the linear track) to the aircraft's displacement and derivatives.

B.3 Equivalence to a Flight Director

It is of great interest to note at this point that this is exactly the same form of equation which describes the deflection of the command bar of the conventional Flight Director. It now becomes clear that if the pilot flies the aircraft in a manner so as to maintain $d = 0$; that is, if he places the end of the predictor on the desired track and keeps it there, he will have the same success, and track with the same characteristics, as if he followed an equivalent Flight Director. Since the tracking performance utilizing a Flight Director has historically been proven to be a success, it may be concluded that the proper use of the predictor will prove likewise.

At the same time, the presence of the horizontal situation display allows the pilot the option of not following a flight director if he chooses while being aware of the true horizontal situation.

Let us now probe more deeply into the equivalence (on a quantitative basis) between the predictor and the Flight Director. First, it must be realized that if the pilot succeeds in maintaining $d=0$ (with either a Flight Director or the predictor), equation 12 completely describes the aircraft motion for any set of initial conditions. This is a second order linear differential equation whose characteristics in the time domain are most adequately described in the literature.

The natural frequency of the characteristic equation is:

$$\omega_o = \frac{2}{T} \quad (B-13)$$

and the damping factor is:

$$\xi_o = .707 \quad (B-14)$$

Simply stated, ω_o is a measure of bandpass (or tightness) of the control and ξ_o is a measure of the damping (or overshoot) of that control. Note that the undamped natural frequency is inversely proportional to the predictor time, the damping factor is fixed, and the aircraft velocity is not a factor at all.

The damping factor of .707 is in the optimum range and corresponds to a 4.32 percent overshoot. Most flight directors attempt to achieve damping ratios which are not so high as to cause a slow closure rate and not so low as to cause a large overshoot. Typical values are from 0.6 (about 10% overshoot) to 0.8 (about 1.5% overshoot).

Typical natural frequencies (ω_o) which have been found to be adequate for tracking during the approach phase are between 0.1 and 0.2 radians per second. Lower frequencies result in "sloppy" performance and poor accuracy, while higher frequencies lead to excessive control and surface activity (pilot workload) with no necessary benefits in accuracy.

From Equation 13 it can be seen that this corresponds to predictor times (T) between 7 and 14 seconds. Since the complex trajectories associated with MLS present a more difficult task than conventional approaches, it is probable that the required natural frequency will tend toward the higher end. Hence, the predictor time will be about 7 seconds.

B.4 Path Capture

Figure B-2 shows two of the possible capture options available to the pilot. Each of these methods makes use of the Predictor but in different ways.

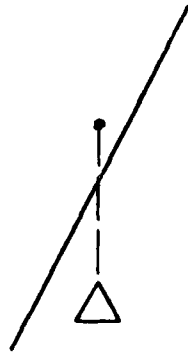
In Option 1, the pilot flies the aircraft, with wings level, to some predetermined relationship to the desired trajectory. At a time which he feels is proper, he banks the aircraft and then maintains that bank angle until the aircraft is almost on trajectory, at which time he rolls out.

In Option 2, the pilot treats the end of the Predictor as a Flight Director command. That is, he places it on the desired trajectory, and attempts to keep it there.

The chief difference between the options, in terms of control cues, is that there is no cue in Option 1 to tell the pilot when to start rolling into or out of the turn. For a smooth bank limited turn, the proper turn initiation time is a function of the closure rate, (i.e., the aircraft speed and capture angle). The consequences of initiating the turn too late are either a large overshoot or a compensating large bank angle.

Let us examine this further, on a quantitative basis, to determine the sensitivity of the resulting maneuver to the turn initiation time. For this purpose, we shall assume that the time required to bank up, once initiated, is zero (or small) compared to the total capture time.

OPTION 1



(a)

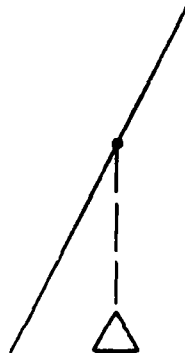


(b)



(c)

OPTION 2



(a)



(b)



(c)

Figure B-2 Two Capture Control Options

Assume an aircraft speed of 250ft/sec, a capture angle of 45° , and that the pilot desires a constant bank angle capture at \emptyset nom. From the geometry, the following can be calculated:

- 1) If the pilot rolls to \emptyset nom late by 1 second, the overshoot will be 176 ft. A 2 second error yields 352 ft overshoot.
- 2) If the pilot wants to capture with \emptyset nom = 30° , and rolls 1 second late, he will have to bank 35° to capture with no overshoot. If he rolls 2 seconds late, he will require 42° of bank angle.
- 3) If the pilot wants to capture with \emptyset nom = 45° and rolls 1 second late, he will have to bank 55° to capture with no overshoot. If he rolls 2 seconds late, he will require 69° of bank angle.

The high sensitivity of this type of capture to roll initiation time (for which the pilot has no dedicated visual cue) is now readily apparent. It may be predicted that poor and inconsistent capture performance will result.

With Option 2, the pilot's task is alleviated by the knowledge that a satisfactory capture will consistently result if he maintains a bank angle time history corresponding to keeping the end of the Predictor on the desired track.

A natural question which arises is whether, based upon performance, it is desirable to attempt Option 1 type captures. To attempt to answer this question, the space trajectory for both types of captures were computed, and are illustrated in Figure B-3.

The plots are based upon an initial capture angle of 40 deg. at a speed of 250 ft/sec. Option 2 uses a 7 second Predictor (1750 feet long) and therefore the capture starts 7 seconds before the aircraft would reach the desired track. The maximum bank angle achieved during the Option 2 capture was 30 deg.

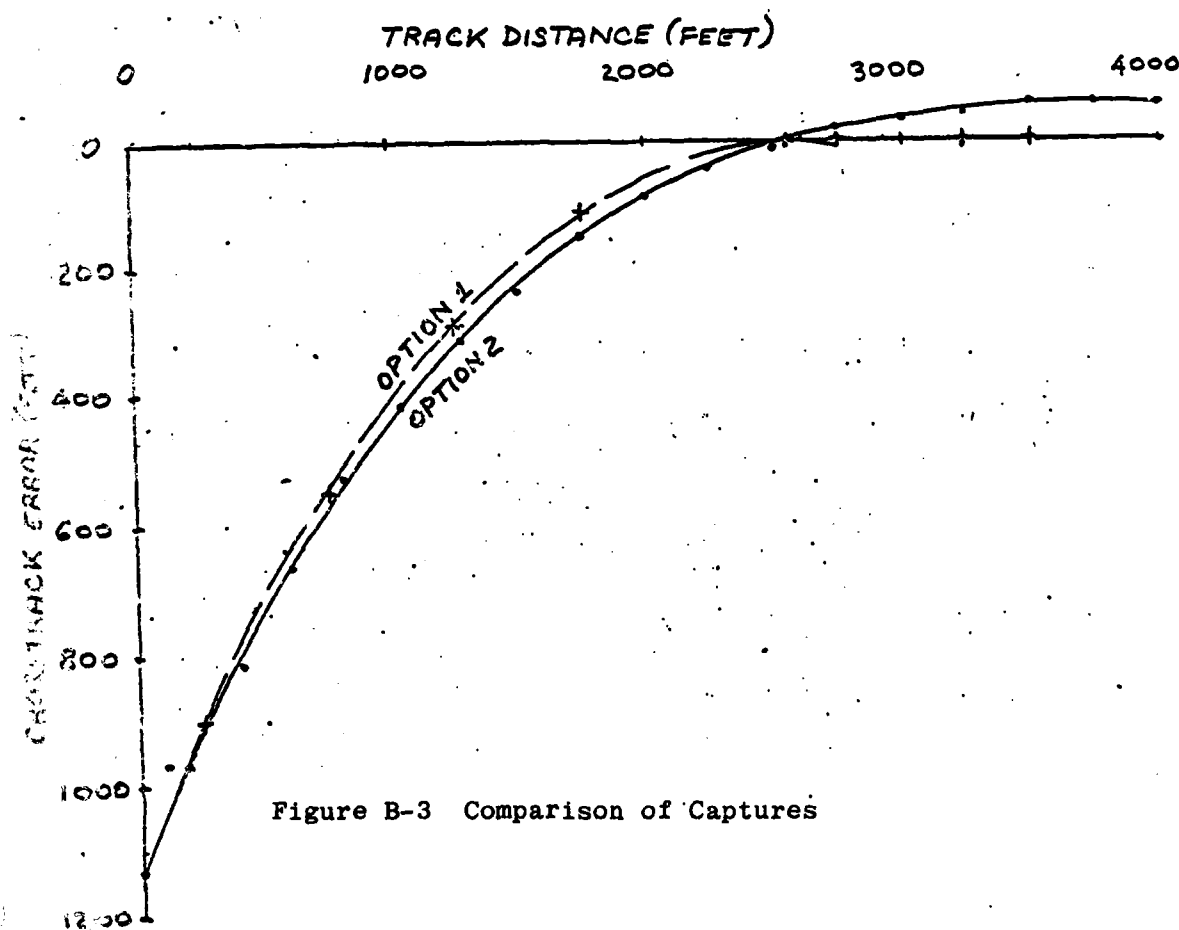


Figure B-3 Comparison of Captures

The Option 1 capture corresponds to that achieved with a constant 30 deg. bank angle and is a circular arc in the space reference. In order to make a tangential capture with a constant 30 degree bank angle, the turn is initiated about two seconds after the Option 2 capture.

As shown in Figure B-3, the perfectly executed Option 1 capture trajectory is almost coincident with the Option 2 capture, except that there is the inherent overshoot (60 feet in this case) associated with the latter. Based upon the overshoot consequences previously cited for performing a nonperfectly executed Option 1 capture, one may conclude that Option 2 type captures will yield better results on the average. This is an area that requires further examination in the Phase II simulation studies.

One additional point worthy of note is that Option 1 capture in Figure B-3 cannot really be made by placing and maintaining a 7 second span Predictor arc tangent to the desired track. For the initial conditions selected, and for a 30° bank perfect capture, the length of the circular arc circumscribed by the aircraft is 2360 feet. Since the Predictor is only 1750 feet long, it is not possible to actually place the Predictor tangent to the track at the beginning of the maneuver. It is only possible to estimate that a visual extrapolation of the Predictor arc (extrapolated an additional 610 ft) would be tangent to the circle. This will undoubtedly make the Option 1 type captures exhibit even greater sensitivity to operator errors.

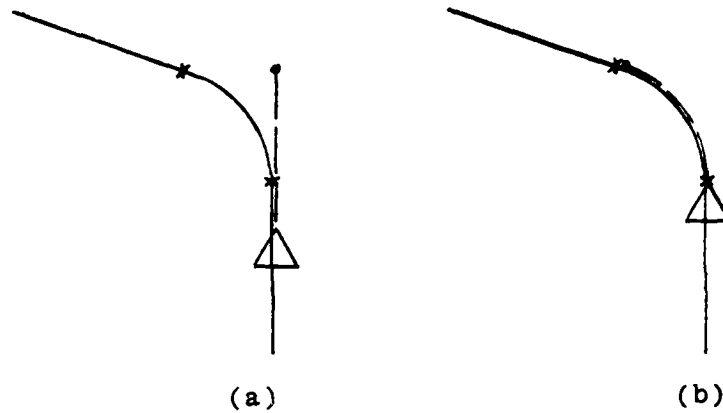
If the pilot waited until he could place the 7 second Predictor arc tangent to the track with no extrapolation required, the resulting bank angle would, of course, be considerably larger. For the case examined here, the bank angle would correspond to 38 degrees.

B.5 Use of the Predictor During Path Transitions

Let us now turn to the problem of transition from a straight track to a circular track and vice versa. Figure B-4 shows two control options for the former case.

Option 1 corresponds to the case where the pilot waits until he reaches, or almost reaches, the transition point, and then rapidly banks the aircraft so that the Predictor arc

OPTION 1



OPTION 2

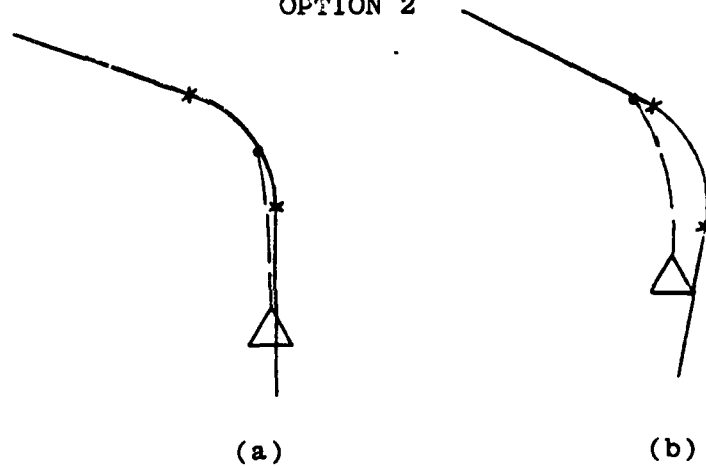


Figure B-4 Two Tracking Control Options/Straight to Circular Path

becomes coincident with the track arc. If he initiates the bank too early, he will fly "inside" the turn; and, if too late, he will fly "outside" the turn. In the latter case: he must first increase the bank angle; he cannot apply the "tangency" mode of control; and, he must, therefore, change the method in which he uses the Predictor.

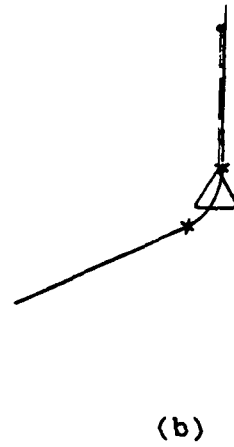
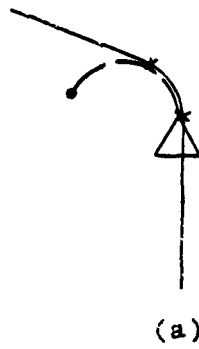
Option 2 corresponds to the case where the pilot always keeps the end of the Predictor on the desired track. In this instance, it is obvious that he will start to bank 7 seconds before he reaches the transition point and, as a result, will fly on the "inside" of the the turn. This is a "built-in" error, inherent in this method of Predictor use, and is exclusive of any other errors involved with how well he uses this method.

This inherent error was calculated for the conditions of flight at 250 ft/sec using a 7 second Predictor, and transitioning to a circular arc track of radius corresponding to a standard turn. The maximum error was 55 ft from the desired track.

It must be remembered that the use of the circular arc originated as one means to smoothly connect two linear track segments intersecting at a waypoint. As such, the circular arc constituted a considerable error from the two linear segments. For instance, if two perpendicular linear segments are smoothed together by a circular arc corresponding to a standard turn at 250 ft/sec aircraft velocity, the closest the arc comes to the waypoint is 2000 ft. Thus, in terms of absolute error, a 55 ft error from the arc is insignificant. However, an inherent error of 55 ft from the displayed arc may have a negative psychological effect on the pilot. The final answer must await the Phase II simulator experiments.

Similar control options exist in the transition from a circular arc to a linear track segment as shown in Figure B-5. In Option 1, the pilot controls the aircraft to keep the Predictor arc tangent to the linear track at the transition point. Upon reaching (or nearly reaching) the transition point, the aircraft is rolled out onto the linear segment.

OPTION 1



OPTION 2

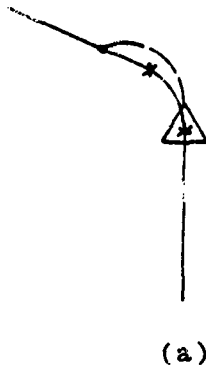


Figure B-5 Two Tracking Control Options/Circular to Straight Path

Again, the maneuver is sensitive to roll-out initiation time. An early exit results in flying "outside" the turn and a late exit brings the aircraft "inside" the turn. In either case, the aircraft will be heading away from the desired track, and the pilot cannot utilize the "tangency" mode of control.

In Option 2 type of control, the pilot again merely keeps the end of the Predictor on the desired track. Again, the roll activity starts 7 seconds before reaching the track transition point. As a result, the aircraft always flies on the "outside" of the turn, again exhibiting an inherent error due to the control means. The actual magnitude of error was not calculated for this case, but it was assumed to be about the same as previously cited. However, the meaning and consequences of this error may be considerably different.

If, upon exit, the pilot finds the aircraft 55 feet off from the linear segment, it is a true error from the desired track. If this linear segment constitutes the last leg of an approach, the error must be corrected before the decision height window is reached. It's acceptability in terms of touchdown performance will depend to a great extent on the "ground rules" for how long the last linear segment must be. All of these problems must be evaluated in Phase II.

APPENDIX C
RELATED USAF, NASA AND OTHER STUDIES

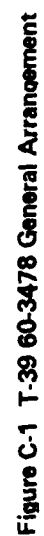
Many studies have been conducted which relate to the subjects discussed herein. A complete listing of material received as a result of the literature search conducted for this investigation is included in Appendix A. The following paragraphs present a synopsis of the USAF Flight Profile Investigation (FPI) Program, NASA Terminal Configured Vehicle (TCV) Program, and other recent studies which produced results directly applicable to the subjects of this study.

C.1 USAF T-39 FPI Program

The Flight Profile Investigation was conducted under the management of the Crew Systems Development Branch of the Air Force Flight Dynamics Laboratory. The program focused on the technical and operational aspects related to performing terminal area instrument approach procedures using precision guidance from the MLS.

The purpose of the FPI was: to determine which flight profiles are feasible in the MLS environment with various levels of aircraft control and display sophistication; and, to establish a baseline for determining the aircraft controls and displays required to fully utilize the segmented and curved approach paths made possible by the use of the MLS.

The research aircraft for the program were two USAF T-39's, tail numbers 03478 and 10649, which are military equivalents of the Rockwell Sabreliner executive jet. These aircraft were modified by The Bendix Corporation's Flight Systems Division to include: the latest Phase III MLS receivers, antenna, controls, and displays; a digital autopilot/flight director/navigation computer; a dual analog autopilot/flight director; conventional electromechanical displays (HSI, ADI); an electronic navigation control-and-display unit (CDU); a programmable 5.7 in. x 5.7 in. color CRT display; autopilot/flight director mode progress displays; an analog autothrottle system; and, a digital data acquisition system. General arrangements of the equipment in these two aircraft are shown in Figures C-1 and C-2. A layout of the instrument panel, side consoles and center pedestal in aircraft 61-0649 is shown in Figure C-3.





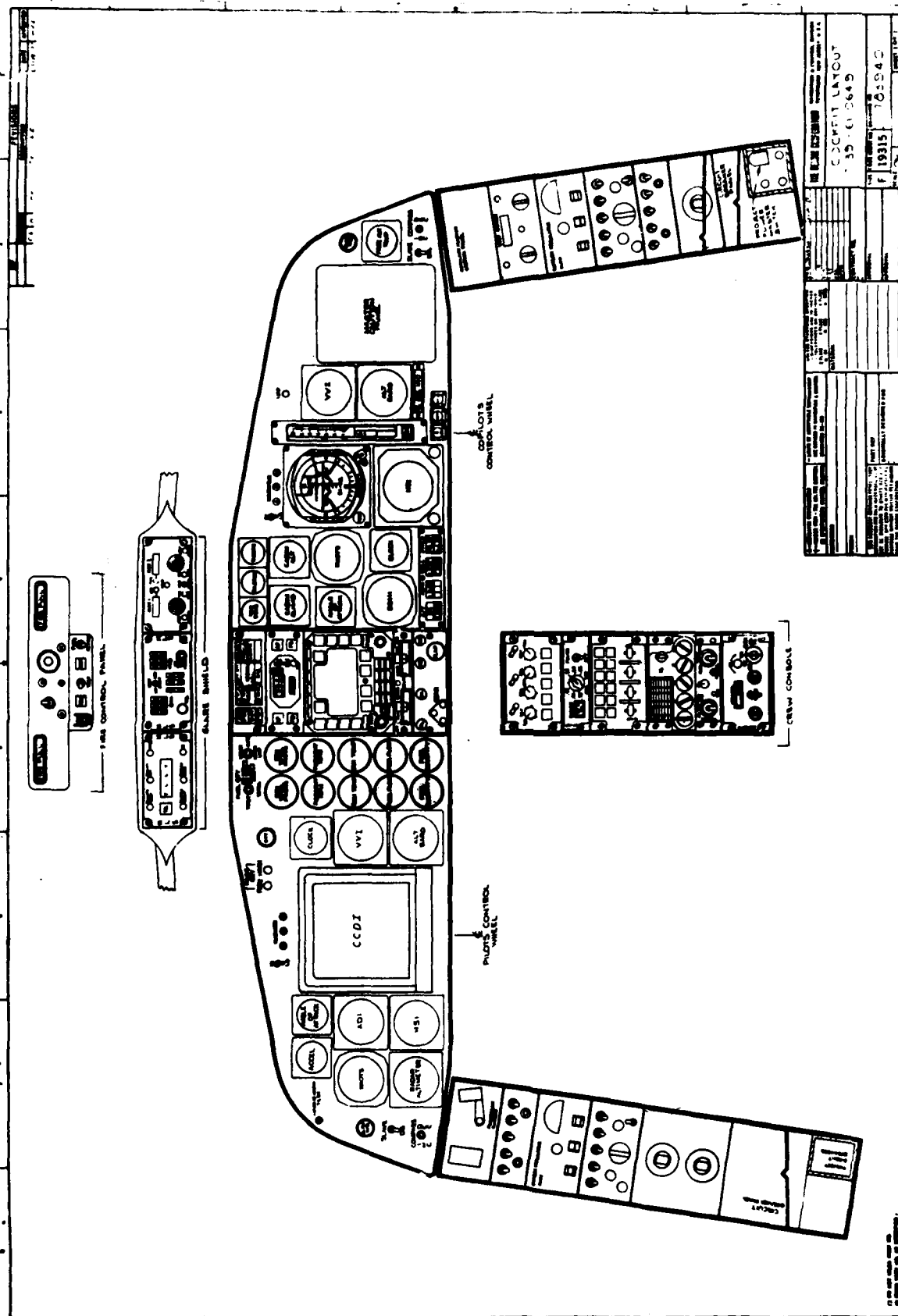


Figure C-3 T-39 61-0649 Cockpit Layout

The aircraft were configured to allow investigations of six levels of MLS flight control and display capability. Level 1 was manual flight control with standard electro-mechanical analog displays (ADI, HSI) of course and glide slope deviation. Level 2 included Level 1 with the addition of an analog flight director system. Level 3 added an analog autopilot. Level 4 was manual flight control with a digital flight director system capable of commanding any desired complex trajectory. Level 5 added a digital autopilot. Level 6 removed the ADI and HSI from the pilot's instrument panel and added an electronic color CRT indicator.

Reference A indicates that flight investigations of Levels 1 through 5, conducted with the MLS at NAFEC and with a radar tracking system used to simulate MLS at Laredo International Airport in Texas, resulted in the following conclusions:

- Aircraft equipped with conventional analog flight control and display systems should be restricted to precision MLS instrument approach procedures similar to existing ILS procedures with final approach intercepts of 7 - 10 nm. This was concluded from tests on profiles as shown in Figure C-4 where the pilot was required to select and fly the azimuth radial corresponding to the initial segment, transition to the intermediate segment at the DME fix and subsequently select the final approach azimuth, and finally capture and track the final approach segment. Many problems were associated with this maneuver. The existing analog autopilot/flight director localizer control law which only looked at raw azimuth deviation could not handle multiple captures (of the initial and final approach segments). No positive guidance other than heading existed on the intermediate segment, therefore, inaccuracies up to 1 nm were experienced. Pilot workload was very high. As a result, it became evident that existing analog systems, unless severely modified, could not be used for complex trajectory flight.
- A digital flight control and guidance system is the most practical method of implementing a complex precision instrument approach capability that fully exploits the volumetric coverage of MLS. With the digital system guidance signals are always computed and accurate tracking

is always achieved.

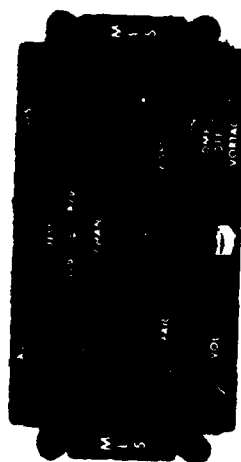
- An aircraft equipped with a digital flight control and guidance system is capable of flying more complex instrument approaches than are acceptable to the pilot and ATC. MLS Instrument Approach Procedures will be limited by pilot and ATC acceptance.
- The information available on current aircraft position and command displays (e.g., ADI and HSI) is inadequate to accurately monitor the aircraft's position and progress on a complex terminal area instrument approach. For this reason further investigations are required to improve and/or augment the conventional displays and to study the benefits of the color CRT display of Level 6. Both of these investigations fall under the scope of this analysis and are discussed within the main body of the report. Only very preliminary work has been done to date in this area of the FPI. Figures C-5 through C-10 show the MLS-related controls and displays on the T-39.

The control laws and filtering schemes developed for the T-39 have resulted in autopilot/flight director performance which provides accurate and stable control from the transition into MLS coverage to touchdown. Some of the problems associated with the MLS transition which occurred during the flight test program, and their solutions, are discussed below. More discussions on this subject are in Section 2.4.4.

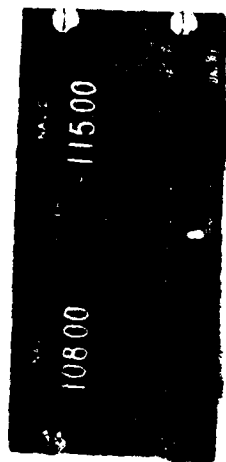
In transitioning from a prescribed RNAV path (the T-39 has a simple VOR/DME system, or a TACAN radial to MLS, lateral discrepancies of up to 0.5 nm were experienced. This was expected due to accuracy differences between the enroute navigation reference and MLS. For the TACAN transition, a capture problem occurred whereby the MLS capture mode (lateral and vertical) would not engage until the aircraft had been within MLS coverage for more than 15 seconds. During this time, and depending on the specific trajectory being flown, errors would accumulate with respect to both the lateral and vertical paths such that a reasonable capture maneuver (of especially the vertical path which may have been falling off at a 5° descent for part of this time while the autopilot was still in the altitude hold mode) was virtually impossible. The problem was caused by the operational logic of the T-39 digital navigation system



PHASE III MLS AUXILIARY DATA PANEL



PHASE III MLS CONTROL PANEL

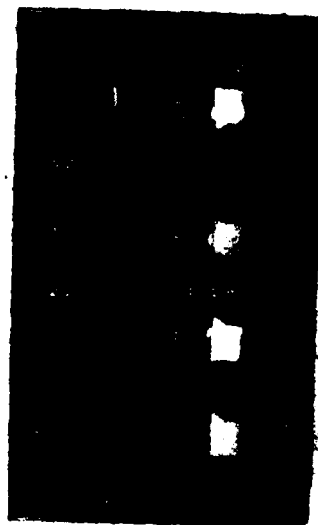


VHF NAV CONTROL
T-39 GLARESHIELD PANEL

Figure C-5 T-39 Glareshield Panels

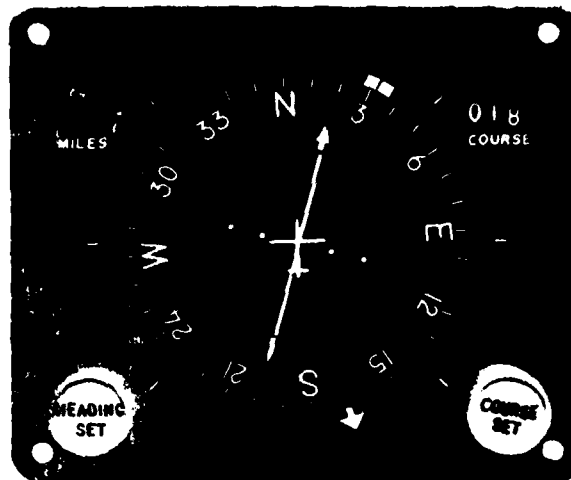


NAV SELECT
T-39 PEDESTAL PANEL

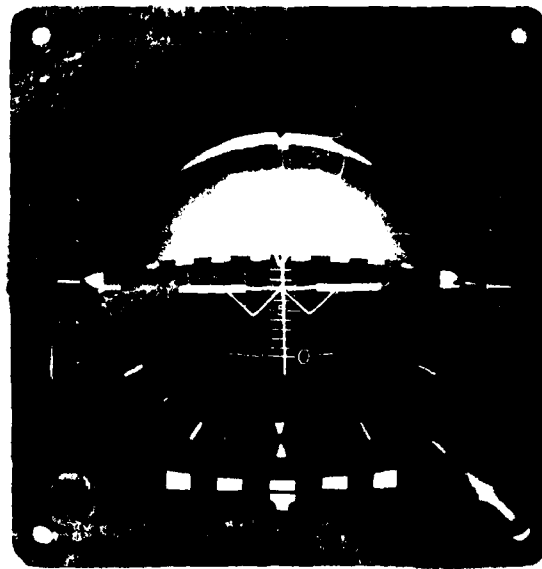


MODE SELECT
T-39 PEDESTAL PANEL

Figure C-6 T-39 Pedestal Panels

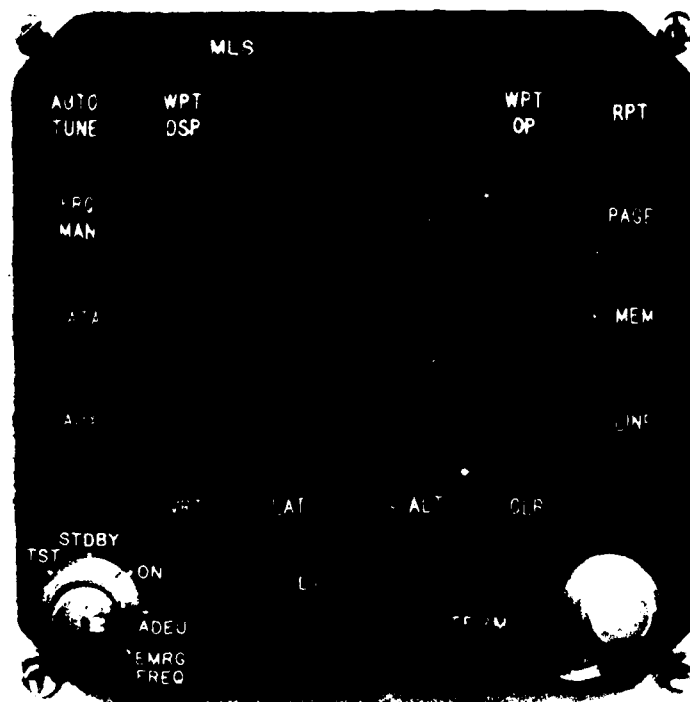


HSI

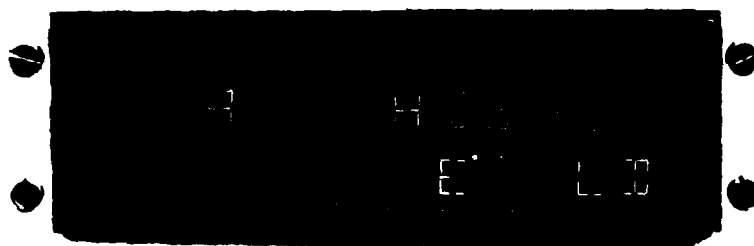


ADI

Figure C-7 T-39 Conventional Displays



NAVIGATION CONTROL-AND-DISPLAY UNIT
T-39 ELECTRONIC DISPLAY

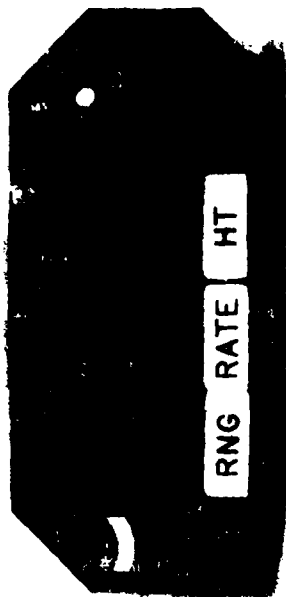


MODE PROGRESS DISPLAY
T-39 ELECTRONIC DISPLAY

Figure 2-8 T-39 Electronic Displays



VERTICAL ANGLE INDICATOR
MLS DATA DISPLAY



DME INDICATOR
MLS DATA DISPLAY



AZIMUTH ANGLE INDICATOR
MLS DATA DISPLAY

Figure C-9 MLS Data Displays

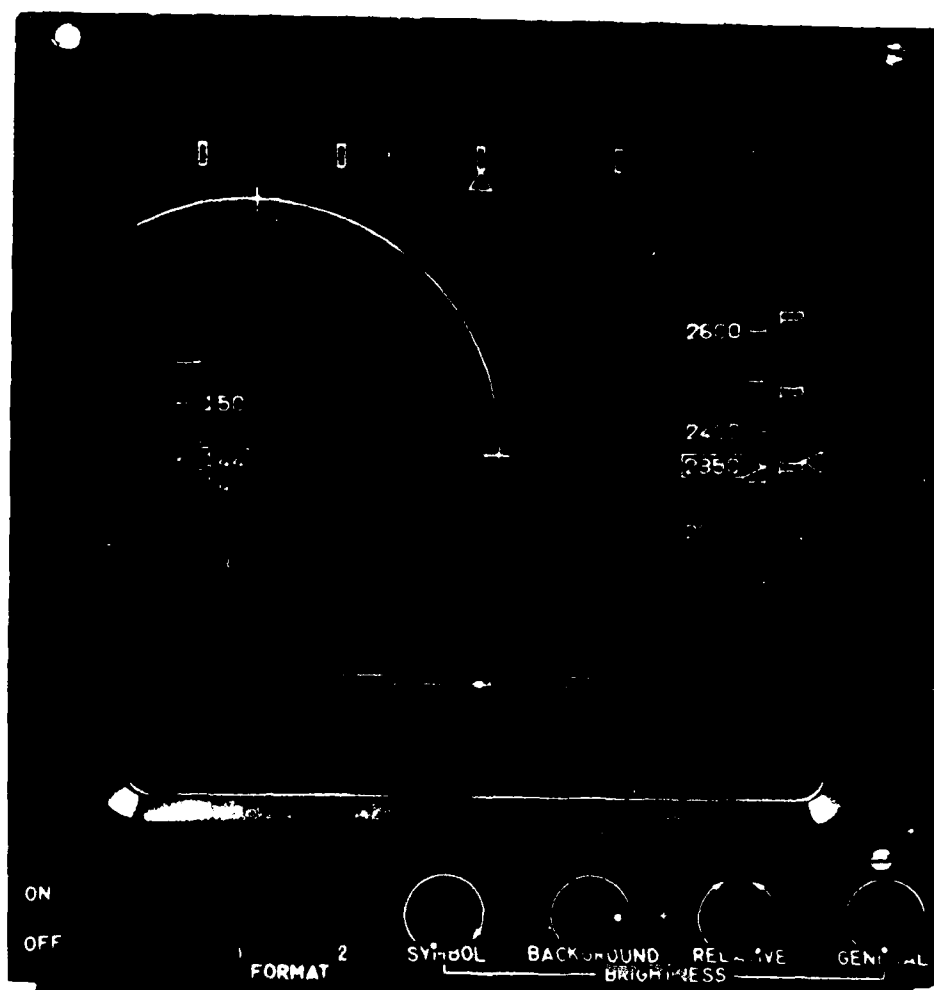


Figure C-10 T-39 CRT Indicator

which does not allow the MLS mode to be armed for engagement, from any mode except RNAV, until validity signals are received indicating that the aircraft is within MLS coverage. Also, once armed, automatic MLS mode engagement was inhibited until the capture logic was satisfied.

For the TACAN transition to MLS, pilot workload was very high. The pilot was required to: monitor his raw MLS data instruments for validity indications; actuate four push buttons in sequence on two different panels (CDU and MSP) to arm MLS after confirming that he was in coverage; and then, maneuver the aircraft, if required, to engage the MLS capture mode. (A detailed set of T-39 operational procedures for an MLS complex trajectory approach are included in Appendix C).

The overall capture problem was partially solved by opening up the capture logic "window" detector on crosstrack deviation to 1.5 nm; thus, providing an immediate engagement after MLS mode arming. This eliminated the pilot maneuver for all but gross errors greater than the detector level. The pilot workload problem can be completely solved by allowing MLS to be armed when not in coverage (as is done with existing ILS modes in present autopilot/flight director systems). No operational problem occurred with the RNAV system because automatic arming and engagement of MLS was integral to the RNAV logic.

In transitioning from VNAV or altitude hold to MLS, vertical discrepancies of up to 500 feet were experienced. These were due in part to normal inaccuracies of the MLS and barometric altimeter but were primarily due to the different zero references for the two systems caused by the curvature of the earth. Figure C-11 shows the discrepancy between MLS derived altitude, which is referenced to the extended runway, and barometric altitude for various distances from the azimuth/DME ground site.

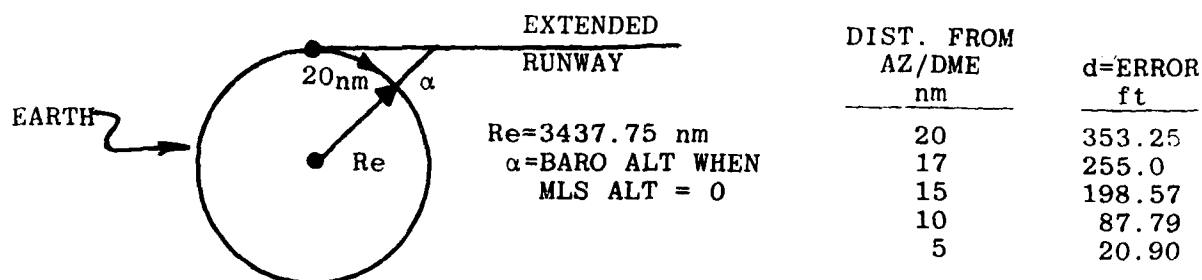


Figure C-11 MLS/Barometric Altitude Reference Discrepancies

The effect of these errors on the automatic flight control system resulted in problems similar to those just described for the RNAV and TACAN transitions. The MLS elevation capture mode was inhibited with large errors (more than 100 feet) and a pilot maneuver was required. For small errors, capture automatically occurred via a smooth automatic maneuver. A far more reaching effect of these errors results from the ATC problem of maintaining altitude separation for aircraft operating in level flight using two different reference systems.

A proposed solution to the MLS vertical transition problem, utilized on the T-39, is to design all complex trajectories such that the initial MLS vertical segment is an extension of the first descent path as shown in Figure C-12. Operationally, the pilot is required to arm the MLS elevation mode and fly in any other pitch axis mode (e.g., altitude hold) to intercept the vertical approach profile. A smooth capture will automatically occur. This also reduces pilot workload and increases operational flexibility by allowing him to approach at any assigned altitude without reprogramming his computer. Using this procedure, the aircraft is always referenced to barometric altitude until the initiation of the published descent. This is completely compatible with current instrument approach procedures.

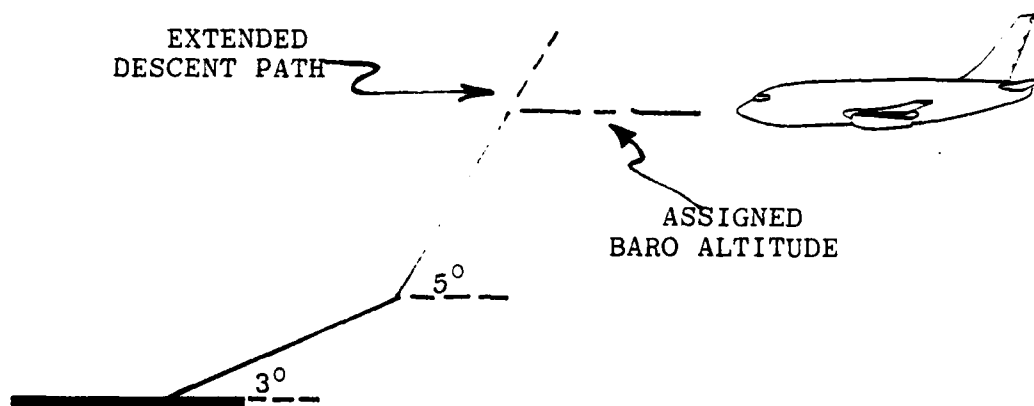


Figure C-12 T-39 Vertical Approach Profile Definition

C.2 NASA 737 TCV Program

The National Aeronautics and Space Administration's Terminal Configured Vehicle (TCV) Program is conducting analytical, simulator, and flight research which will support civil air transportation improvements in:

- terminal area capacity and efficiency
- approach and landing in adverse weather
- operating procedures to reduce noise impact

In this research, major emphasis is being placed on the development of advanced aircraft flight control-and-display concepts for application to operations in future high-density terminal-area environments. These terminal areas will be equipped with new landing systems, navigational aids, data links and other air traffic control systems now being developed by the FAA and DOT.

The TCV research aircraft is a Boeing 737-100. It contains a special research flight deck located about 20 feet aft of the standard cockpit. From the aft flight deck the aircraft can be flown in a fly-by-wire mode using advanced electronic display and digital automatic flight controls. The arrangement of palletized research installations is shown in Figure C-13. The instrumentation layout of the aft cockpit

is shown in Figure C-14.

Key elements of the NASA MLS are:

- Integrated digital navigation, guidance, display and control system
- Automatic 3-D flight profiles with short (1-1.5nm) final approach segments to touchdown
- Definition of cockpit displays to accurately follow curved approaches--each pilot has 3 monochromatic CRT displays: EADI, EHSI, CDU with keyboard
- Development of advanced automatic flare control laws to reduce present-day touchdown dispersions

Pertinent results of the TCV research relative to control- and- display follow.

1) Reference 35 presents the results of a flight evaluation of two electronic display formats for the approach to landing under instrument conditions. The evaluation was conducted for a baseline electronic display format shown in Figure C-15 (described in reference 63) and for the same format with the addition of horizontal situation information, consisting of a perspective runway symbol and a relative track angle indicator, on the EADI (see Figure C-16). Flight path tracking performance and pilot subjective comments were analyzed with regard to the pilot's ability to capture and maintain a 3nm straight-in, 3° descent MLS path while flying a flight director approach.

The baseline format on the EADI consists primarily of the aircraft attitudes, flight path information and flight path deviations. The EHSI presents the aircraft symbol, a 30-second trend vector which predicts aircraft position information 30 seconds ahead, an extended runway center line, and a digital readout and scale of the present track angle.

The integrated situation information format contains the addition of the runway symbology and relative track information on the EADI. The EHSI format remained identical to the baseline configuration.

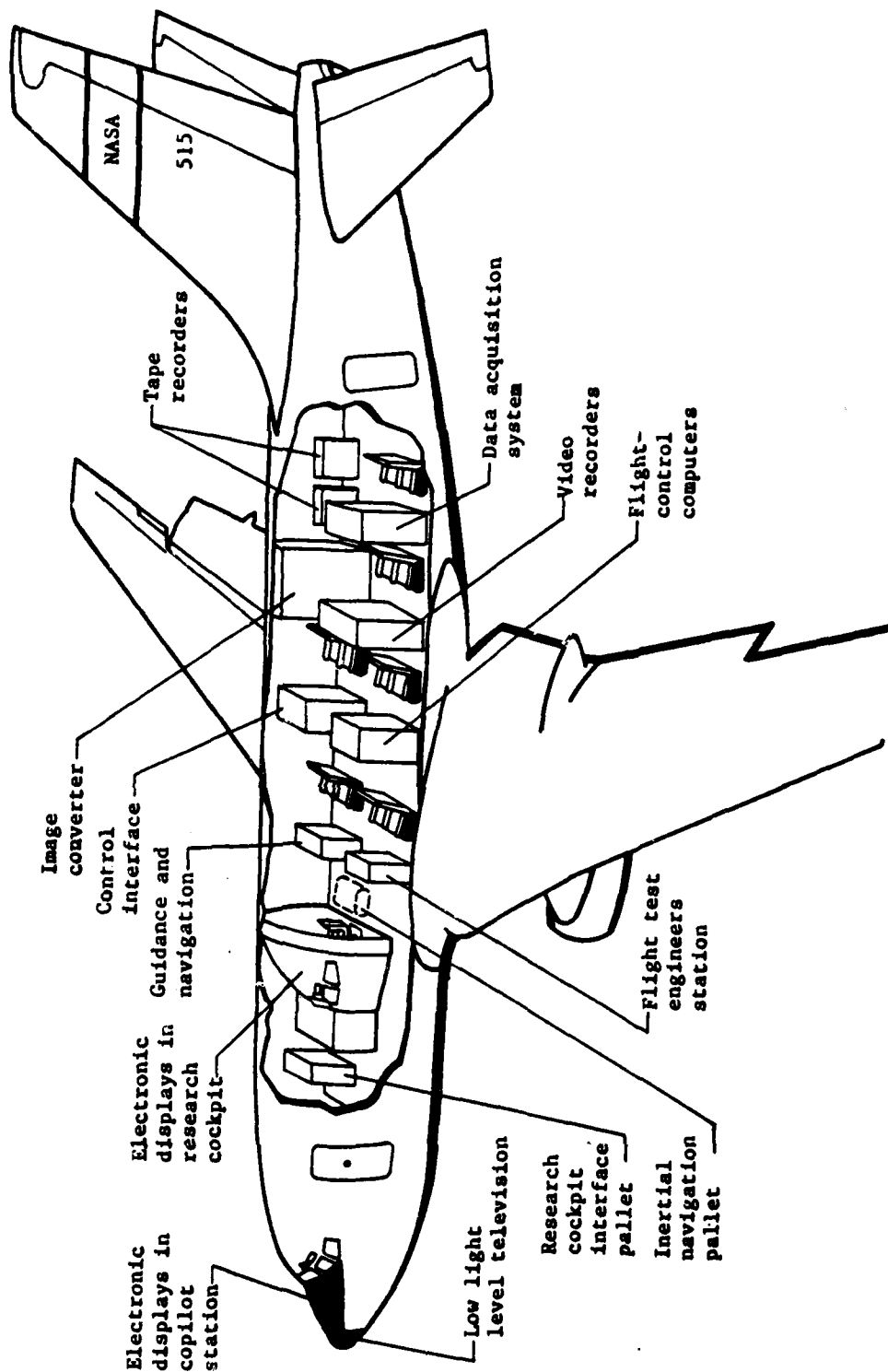


Figure C-13 Internal Arrangement of TCV B-737



Figure C-14 AFT - Flight - Deck Display Arrangement

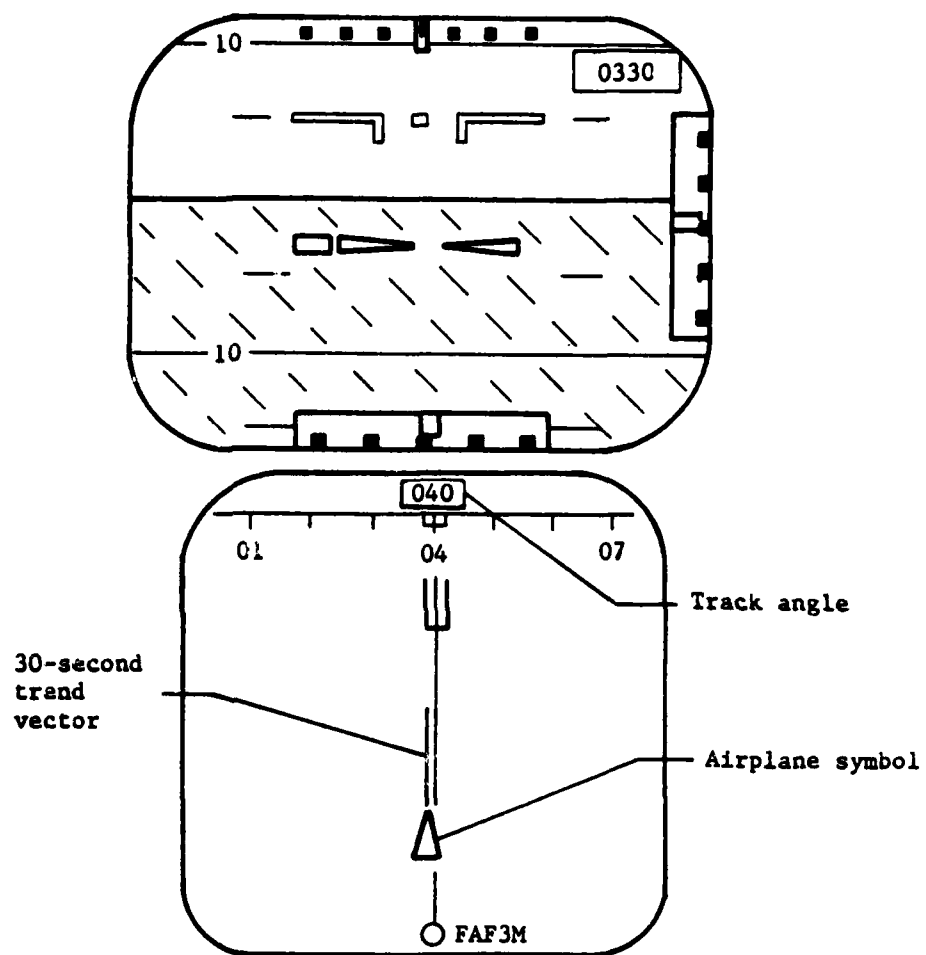


Figure C-15 Base-Line Situation Display Format

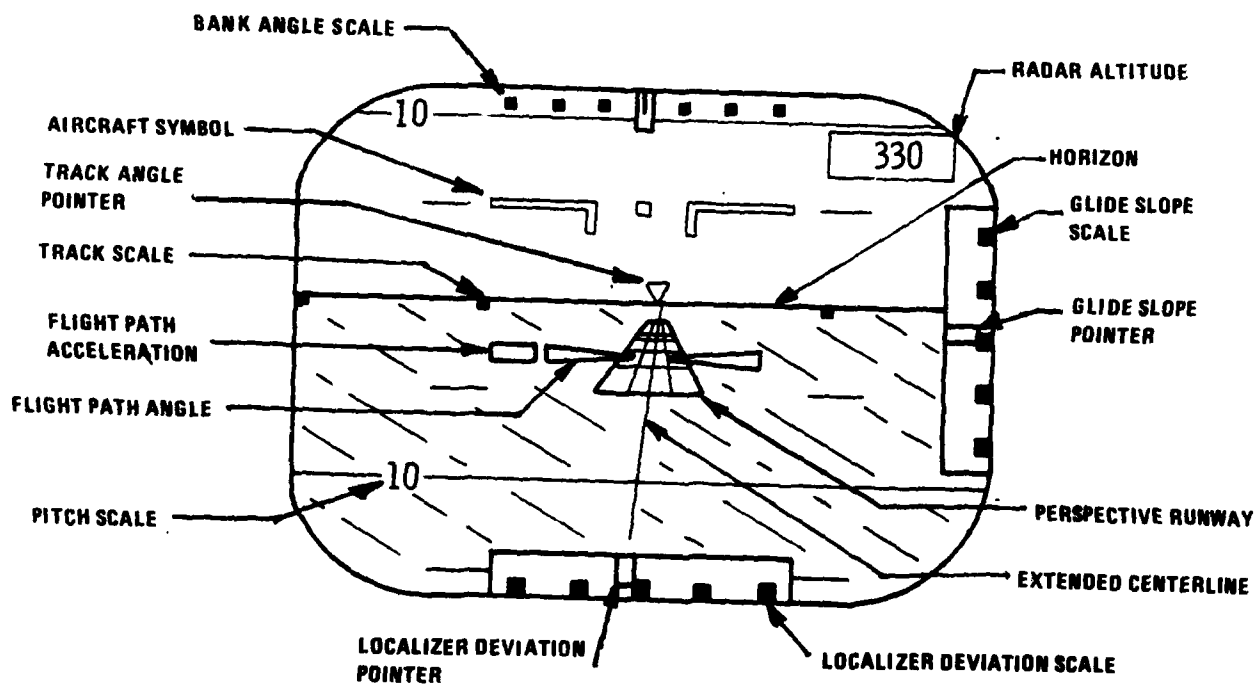


Figure C-16 Integrated Situation Display Format

The perspective runway symbology, drawn on a 30° by 40° field of view, includes the basic outline of the runway with an extended center line drawn 1 nm before the runway threshold to the horizon. A magnification factor of 0.3 to 0.5 results, depending on pilot seat position. The runway symbol represents a runway 3048 m (10,000 feet) in length and 45.72 m (150 feet) in width. Four equally spaced lines were drawn perpendicular to the center line of the runway at 304.8 m (1000 feet) intervals that start 304.8 m beyond the runway threshold. Two lines parallel to the center line of the runway were drawn to divide it into equal quarters. The mathematics of drawing the runway symbology are detailed in reference 35.

The relative track angle indicator pictorially shows the inertially reference track angle of the airplane relative to the runway heading. Relative track angle information was indicated by a tab that moved along the horizon line of the EADI. A track scale, referenced to the runway heading in 10° increments, was drawn on the horizon line of the EADI. Using the tab and track scale, the pilot could determine the magnitude of the relative track angle of the airplane to the runway.

Figure C-17 depicts the flight profile used to conduct the experiment. Approaches were flown with and without an initial 0.1 nm offset from the final approach segment. The test procedure required the pilot to execute the curved approach by using both the EADI and EHSI. Once the turn was complete, the pilot was instructed to use primarily the display information on the EADI to track the lateral and vertical flight paths.

Test results, shown in Figures C-18 through C-23 indicated that the integrated situation display format increased flight path accuracy.

The pilots commented that the integrated situation format brought about a better understanding of the airplane's position and trajectory relative to the runway and the extended runway center line. This understanding enabled the pilots to more quickly recognize and recover from a large lateral path deviation with confidence. In addition, pilot corrective inputs could be modulated depending on the size of the error and the remaining distance to the runway

threshold. They commented that the integrated situation display reduced pilot workload for the lateral task by eliminating the need to scan the EHSI and enabled him to spend more time on the glide path task. The pilots felt that the lateral path guidance provided by the map display was not sufficient for a close-in final approach, even with the map scale set for greatest resolution (0.394 nm/cm).

These flight test results compare with the simulation study described in reference 39.

2) Reference 39 presents the results of the pilot simulation study of the two electronic display formats described above.

Initial display information development indicated that one of the strongest cues available to the pilot from the runway geometry is the symmetry (slant) of the runway with lateral displacement. The pilot may determine from the runway symmetry, regardless of his altitude or relative heading, whether his aircraft is on or is displaced to the left or right of the runway center line. Lateral deviations outside the width of the runway borders were easily determined although precise determination of the magnitude of displacement was not possible.

Aircraft altitude, aircraft range to the runway threshold, and deviations from the glide path were difficult to assess solely from geometry cues. While growth rate and runway size did give the pilot a feel for closure rate at ranges less than 3704 m (2nm), estimates of range and altitude were not consistent, particularly when the pilot was looking at runways of various lengths and widths. The pilot used objects such as trees, houses, or roads along his approach path to judge range and altitude.

Another important cue found to be necessary for lateral approach path tracking is relative heading between the longitudinal axis of the aircraft and the center line of the runway. The pilot must know the relative heading since very small differences cause the aircraft to fly away from the localizer (or MLS lateral path) course. This situational information was depicted on the EADI as a track angle pointer and scale. Track angle, instead of heading, was used as a reference since this is the desired information for the landing-approach task.

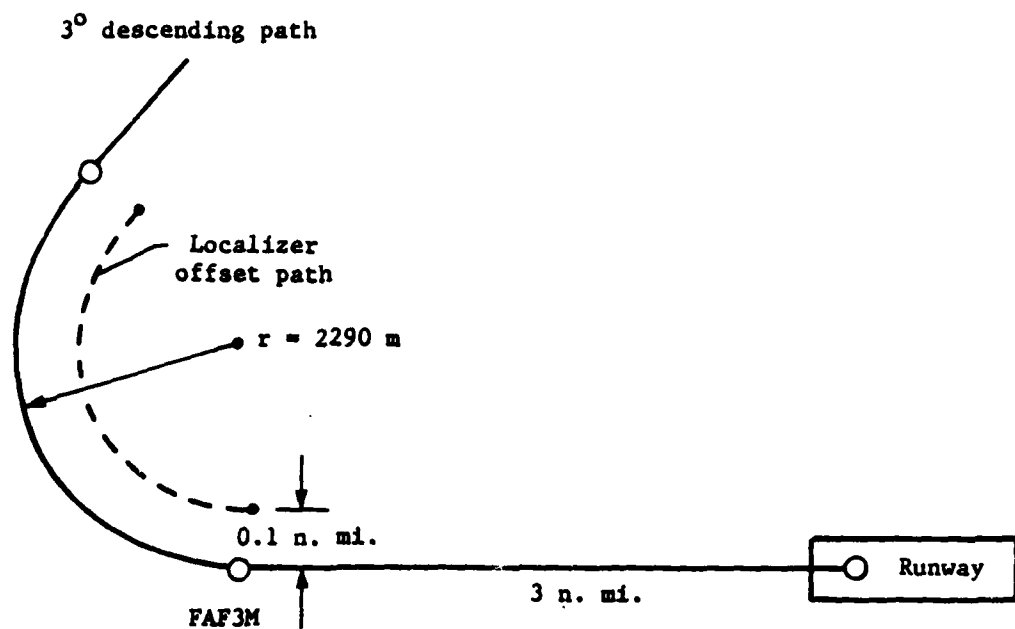


Figure C-17 Plan View Of Approach Path To Runway 04 At National Aviation Facilities Experimental Center

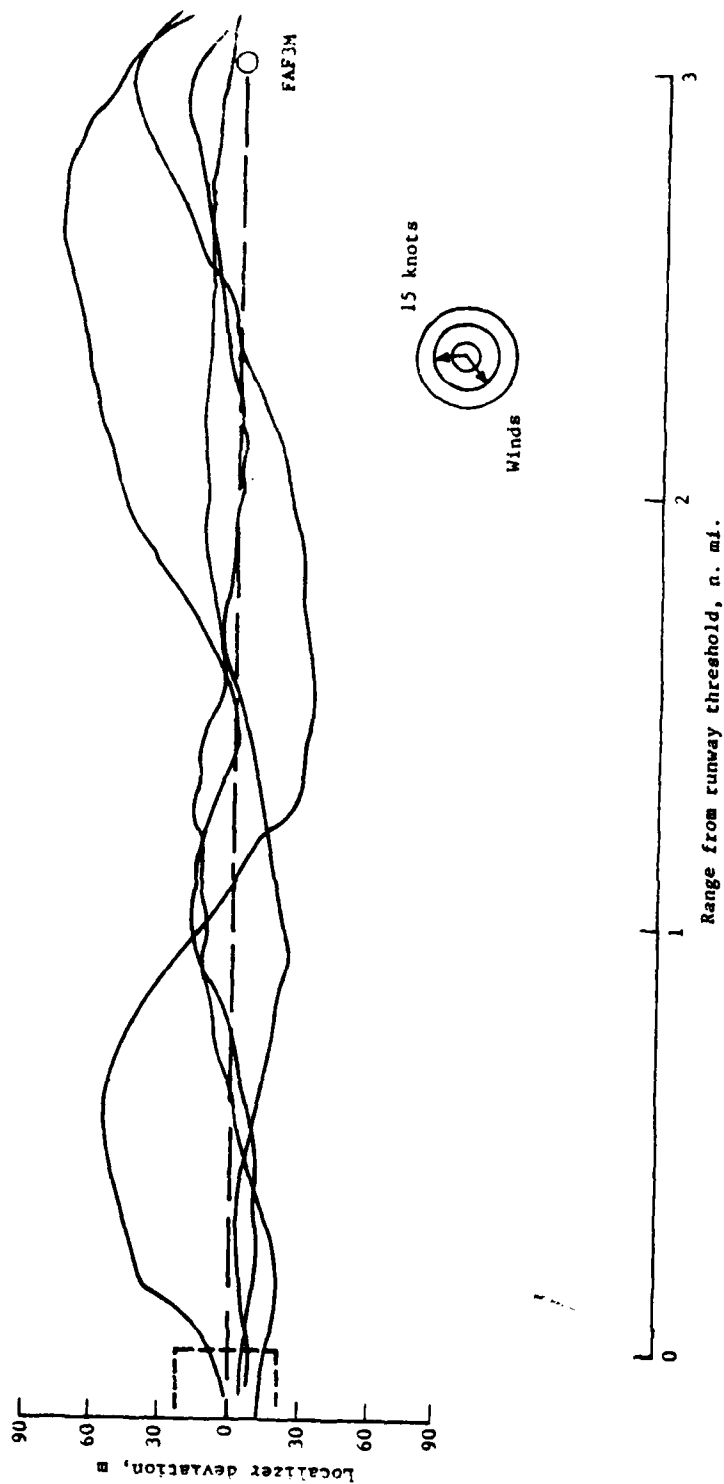
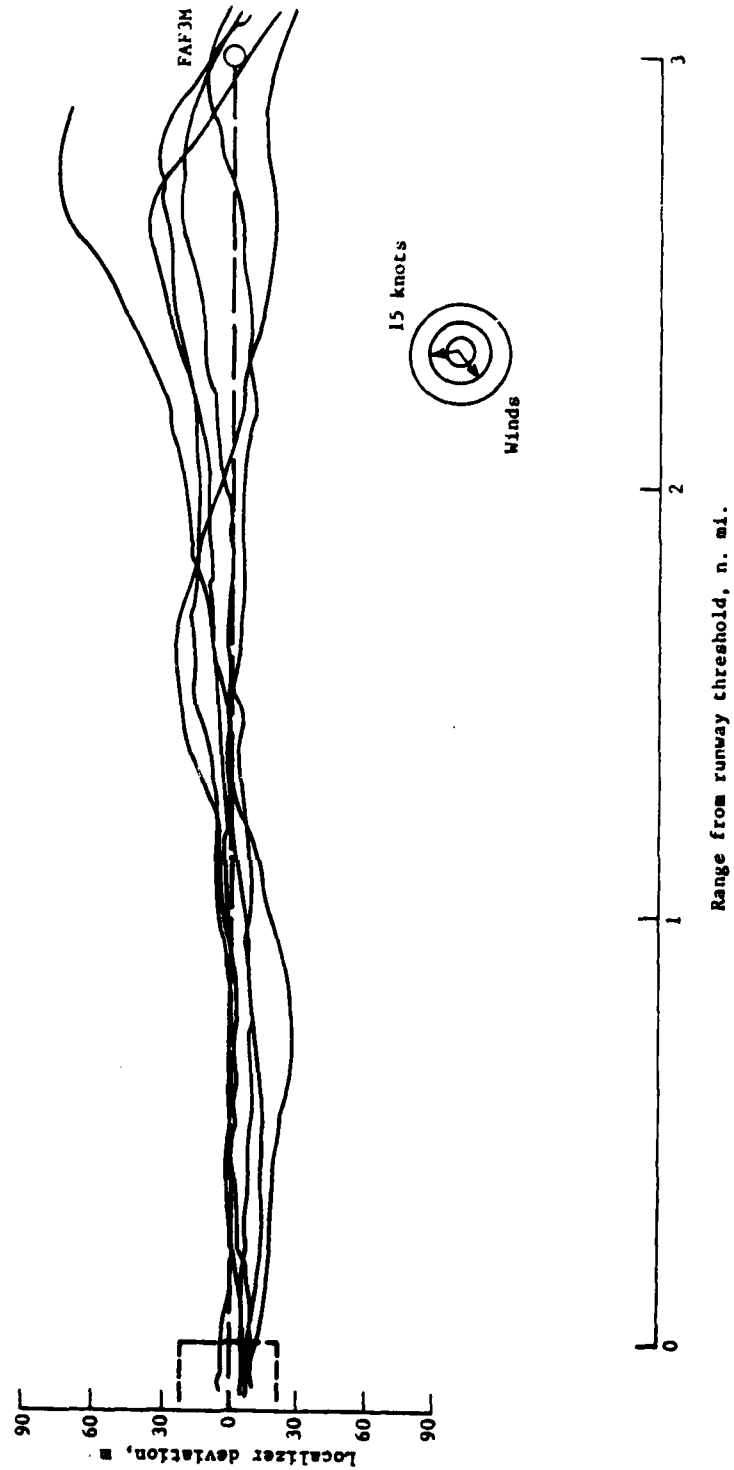


Figure C-18 Localizer Tracking Performance Using Base-Line Situation Display Format



C-25

Figure C-19 Localizer Tracking Performance Using Integrated Situation Display Format

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CONTROL-DISPLAY INVESTIGATION OF COMPLEX TRAJECTORY FLIGHT USIN--ETC(1

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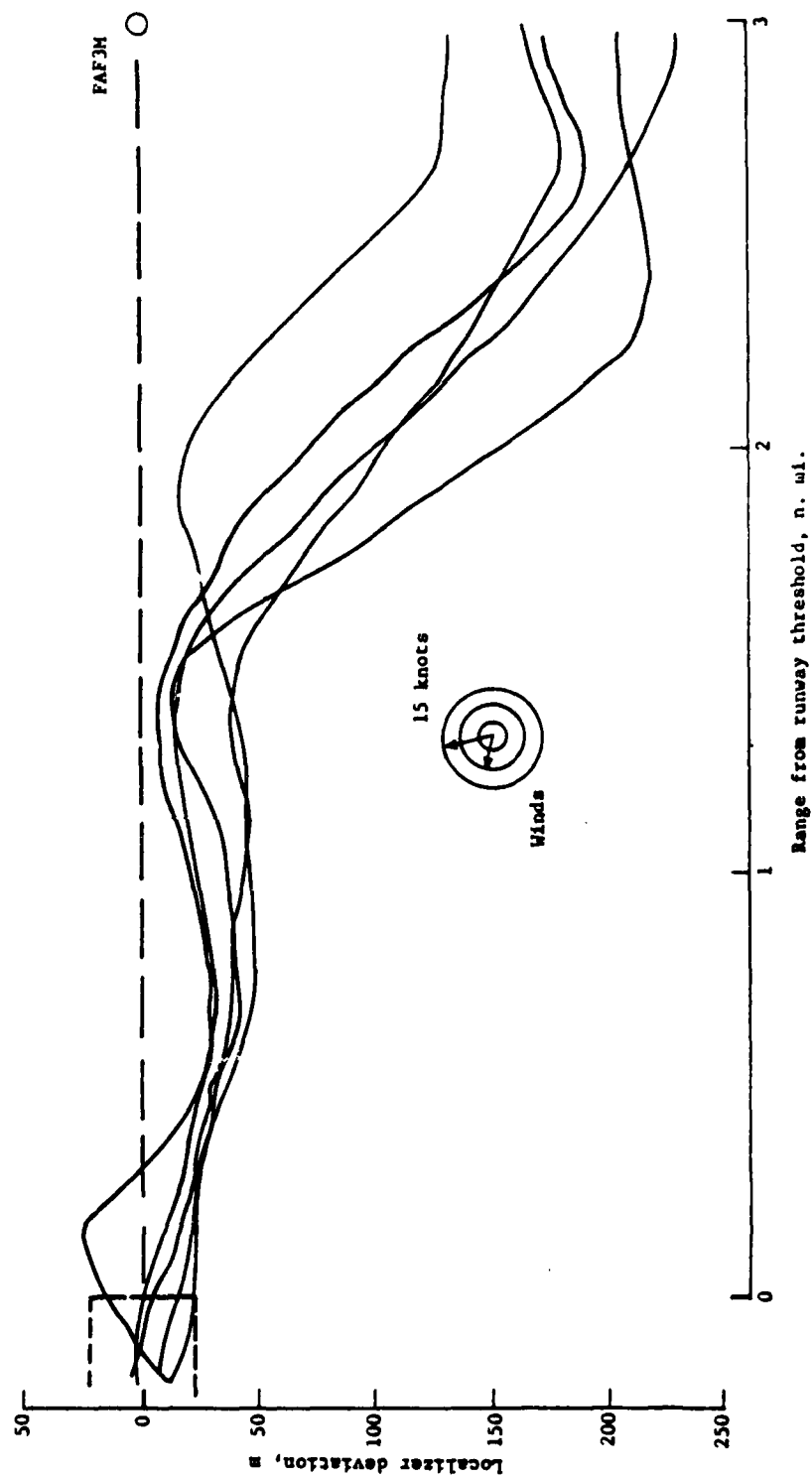


Figure C-21 Localizer Tracking Performance With Initial Offset Using Base-Line Situation Display Format

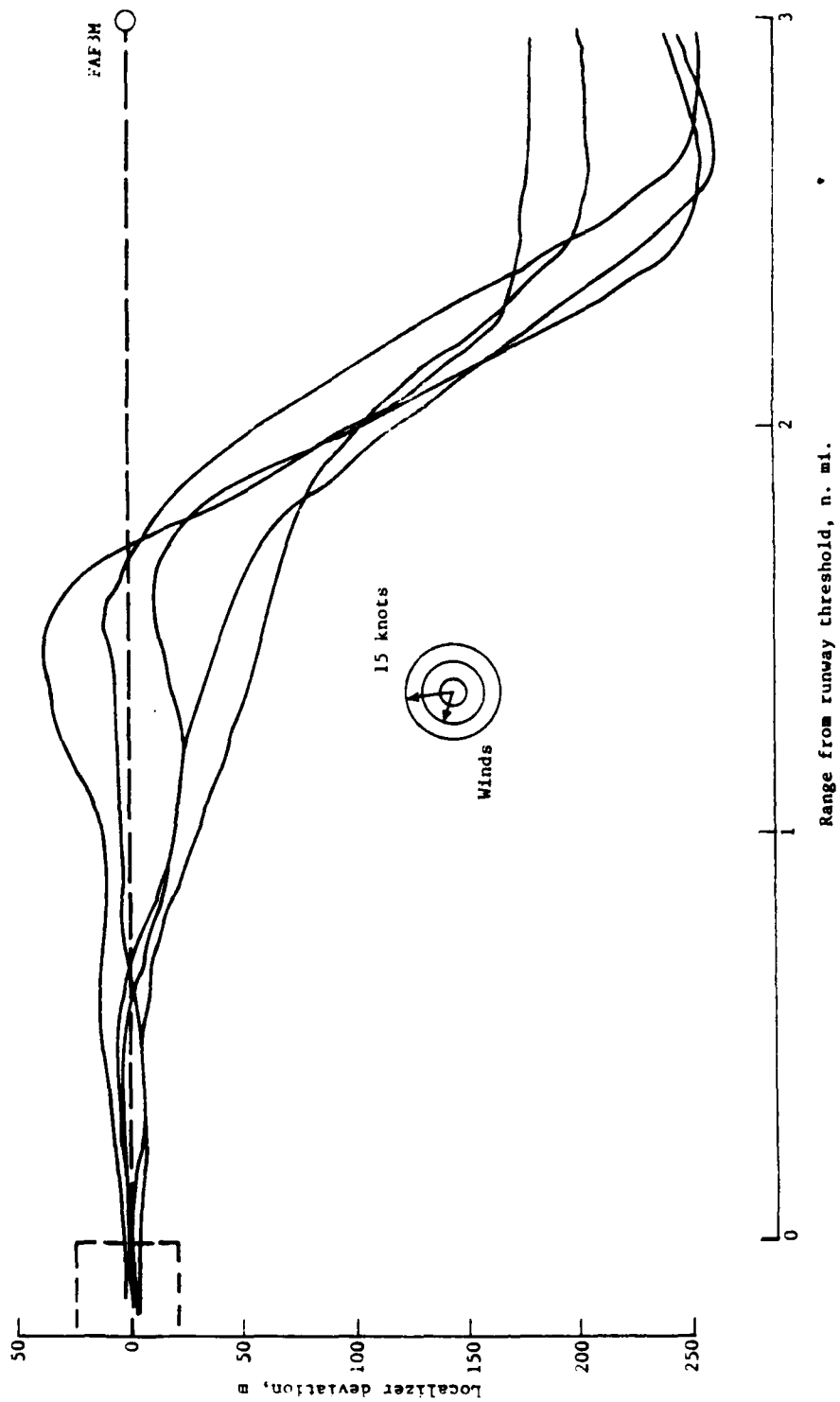
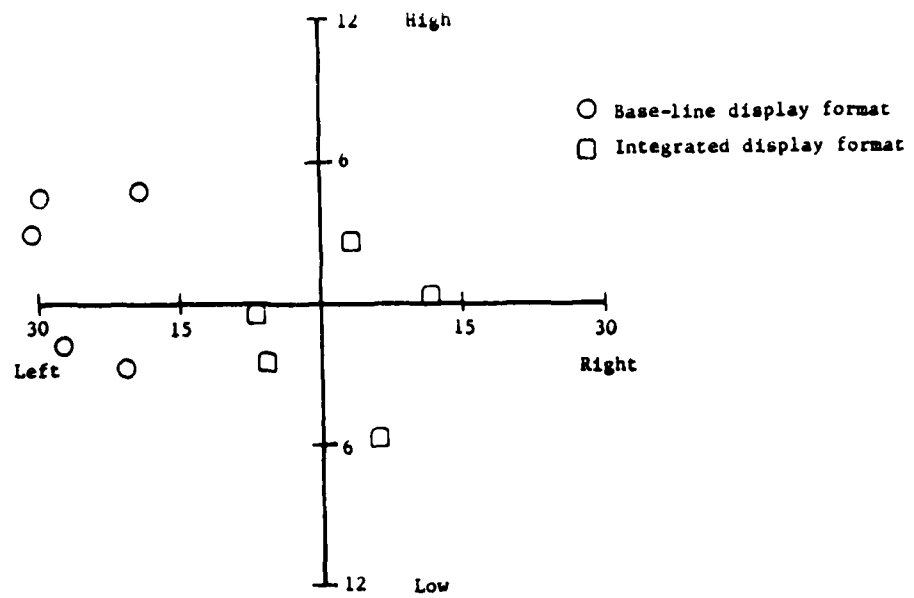
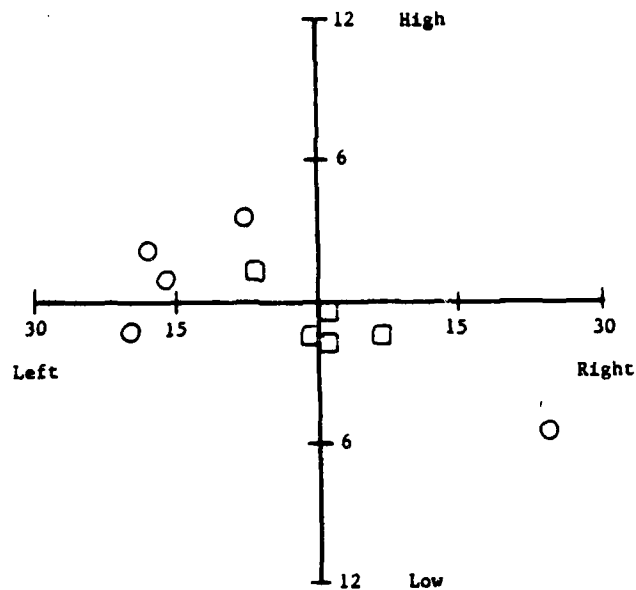


Figure C-22 Localizer Tracking Performance With Initial Offset Using Integrated Situation Display Format



(a) 61-m window data.



(b) 30.5-m window data.

Figure C-23 Window Data Of Glide-Slope And Localizer Deviations
All Scales In Meters

C.3 Other NASA Studies

1) Reference 51 presents the results of a pilot scanning behavioral study in which a series of approaches were made by airline-rated Boeing 737 pilots in an FAA qualified simulator. This simulator contained standard electro-mechanical instrumentation. A nonintrusive oculometer system was used to track the pilot's eye-point-of-regard throughout manual and coupled VFR, Category I and Category II approaches.

All tests were started at 19 km (12 miles) from the runway threshold and approximately 415 m (1360 feet) above the ground. The first 6 km (4 miles) were used to stabilize the aircraft on the flight path and check the oculometer calibration. At 13 km (8 miles) data recording was started and continued throughout ground rollout or until the approach was aborted.

Observation of the pilot scan patterns during the instrument portion of the test indicated that the pilots used the center of the flight director (ADI) as the primary look-point and moved from there to an instrument and then came back to the center of the flight director. Only rarely did a pilot check more than one instrument before returning to the center of the flight director. The bar graphs shown in Figure C-24 show a comparison of the percent time spent on the instruments for both the manual and coupled modes with no atmospheric turbulence. Each contains the summary data for the entire approach. It was found that the percent time spent on the various instruments does not vary by more than a few percent for the different phases of the approach (straight and level, glide slope capture, or descent). The clock, radar altimeter, and ADF are not included in this figure since they were used very little. Of particular interest is the comparison of time spent on the flight director (approximately 73 percent in the manual mode as compared to 50 percent for the coupled mode) and the airspeed indicator (13 percent in manual and 22 percent in coupled). It should be noted the throttles were controlled manually.

The introduction of turbulence did not greatly affect the pilot's scanning behavior in terms of the percent time spent on various instruments. For both the manual and coupled cases the time on the flight director increased

7 PILOTS, 3 RUNS EACH

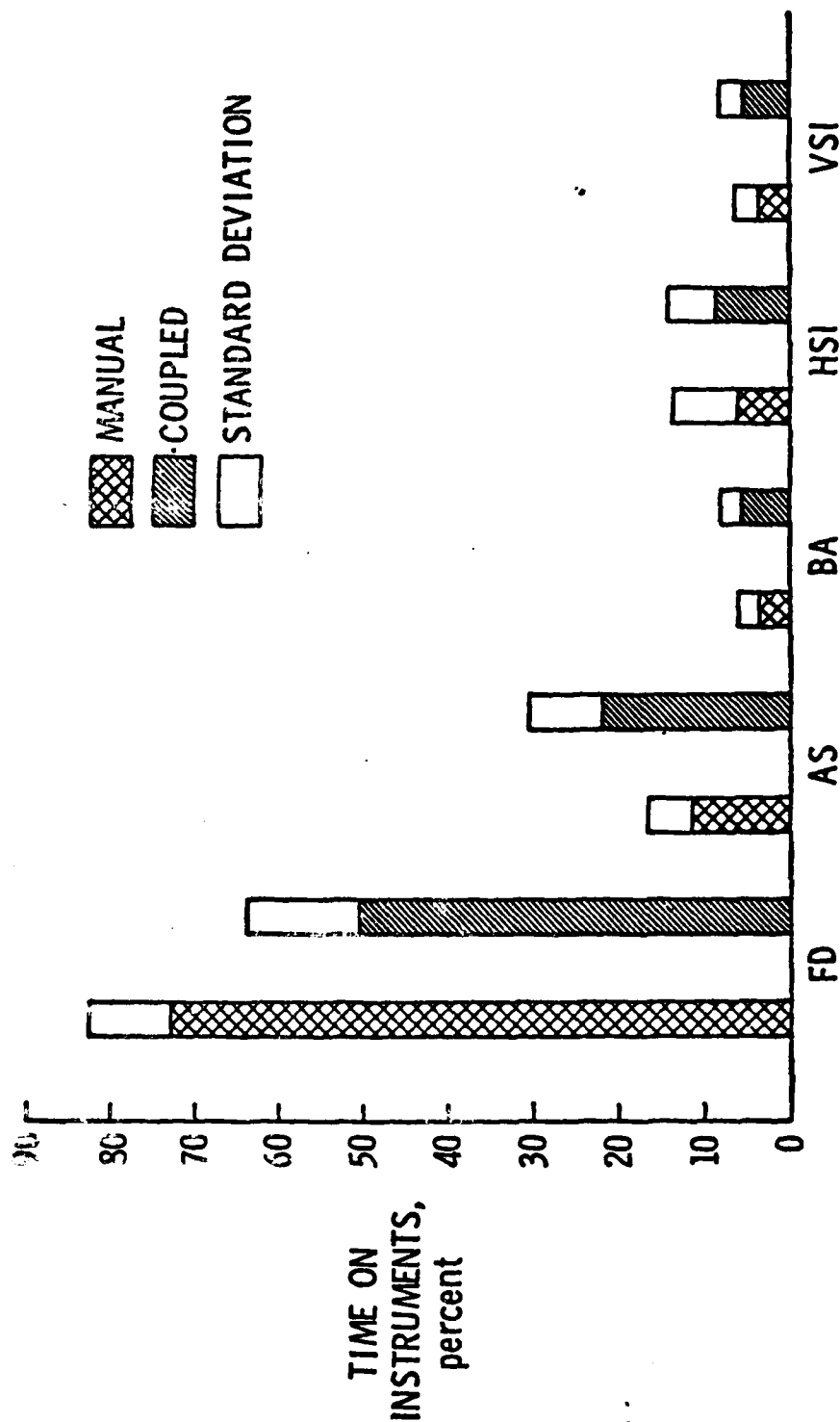


Figure C-24 Percent Time On Instruments For Manual And Coupled Approaches

by about 3% with this being primarily taken away from airspeed.

Pilot comments indicate that, while they were not necessarily aware of the differences in scan as a function of the control mode (manual or coupled), they attribute the change to the different type of mental picture required. For the manual mode, they must keep a mental picture of where they are and where they are going, which is best obtained from the flight director. Any visual interruption from it requires that they reform that picture upon returning to it. For the coupled mode, they are primarily checking needle positions and, consequently, are free to scan more instruments.

2) Reference 46 presents the results of a simulation study performed at Ames Research Center which investigated: multiple, curved, descending approaches that merge on a common final approach within 1 mile of the field; parallel runways certified for simultaneous and independent operation during IFR conditions; 1 minute separation at the missed approach point; and, the use of traffic situation displays (TSD) in the cockpit coupled with a distributed air traffic management system between the air and the ground. The objective was to develop solutions which would evolve a procedural system that could safely increase air traffic density. Three groups, each consisting of three commercial airline pilots and two air traffic controllers, flew a combined total of 350 approaches. Three fixed-base cockpit simulators were supplied with computer generated TSD's and flight instruments, all combined on a 25.6 cm x 25.6 cm (10 in. x 10 in.) CRT as shown in Figure C-25. The controllers were supplied with a terminal area map display and digital status information. The map display consisted of a 20.7 cm x 20.7 cm (12 in. x 12 in.) CRT upon which all traffic within 5 nm of the field and the five approach routes for each of the two runways were displayed (see Figure C-26). A keyboard and CRT were provided for data entry and readout of aircraft status (i.e., landing order, aircraft type and call sign, approach route, speed, heading, and altitude).

In the study, two divisions of air traffic control responsibility were compared: (1) a ground-centralized system in which controllers were responsible for maintaining separation as well as for issuing sequence commands and

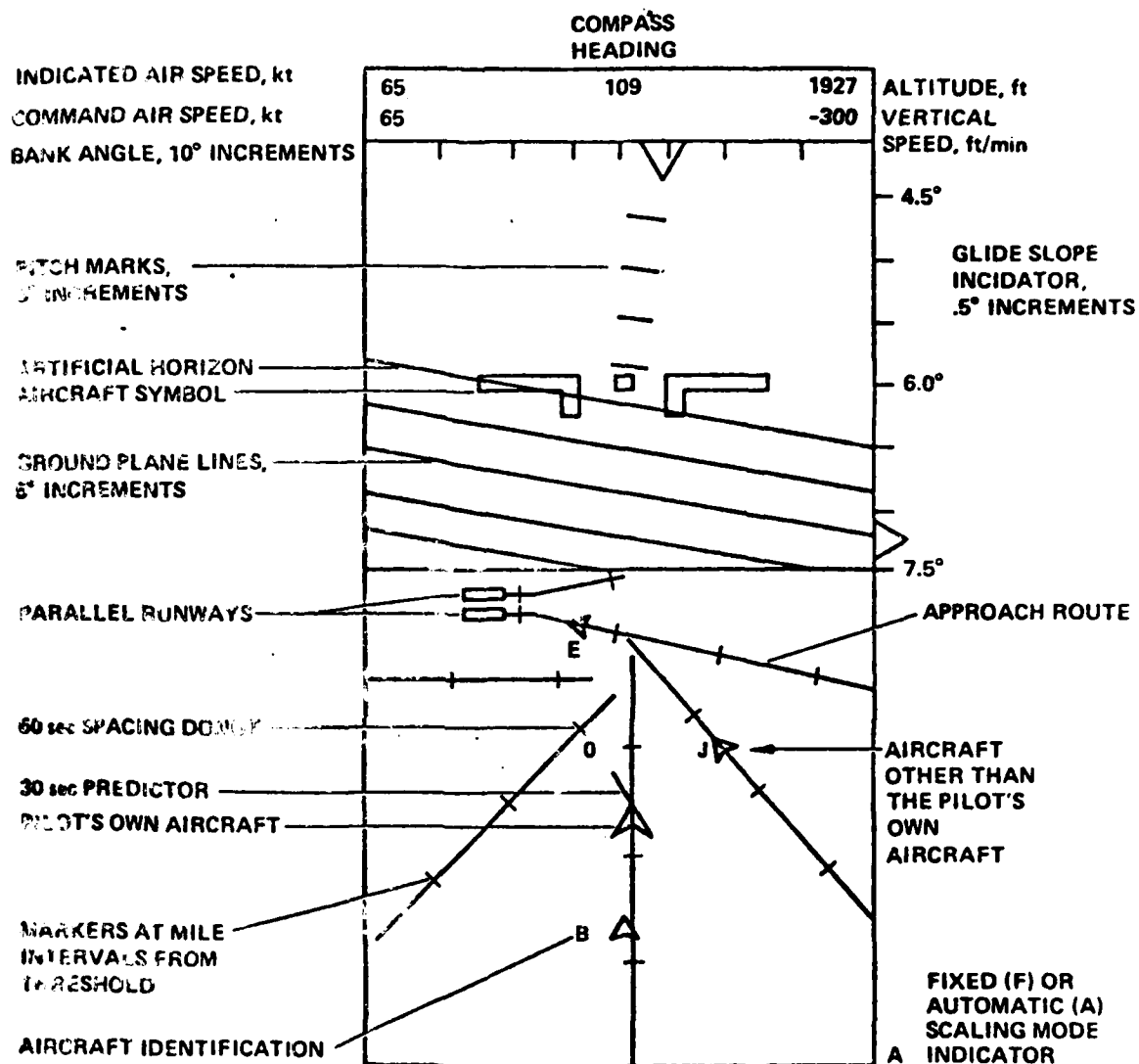


Figure C-25 Vertical Situation Display (Upper) And Traffic Situation Display (Lower) Serving As The Pilot's Flight Instruments

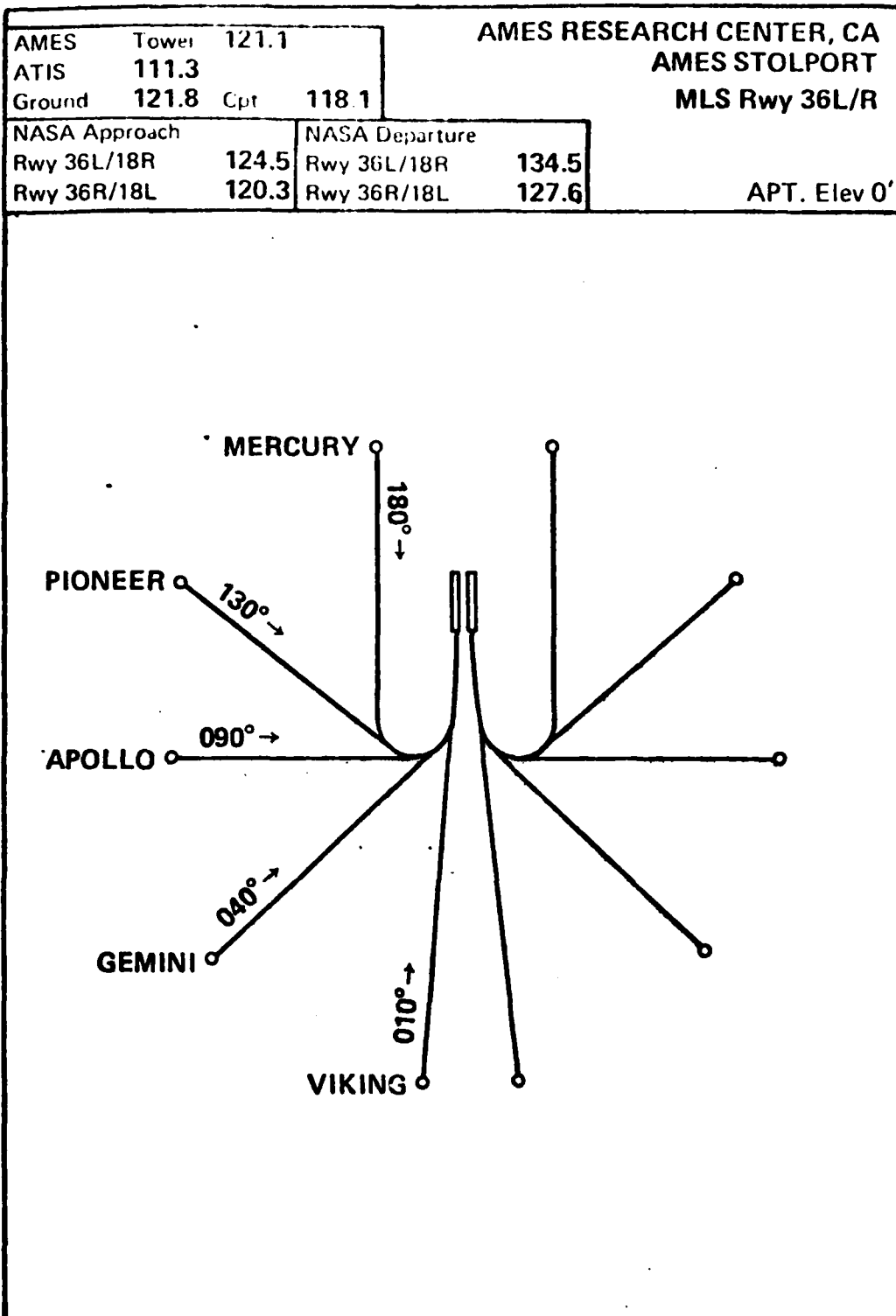


Figure C-26 Multiple Approach Routes With Common Final Approach Path To Two Parallel Runways

(2) a distributed management system in which controllers were only responsible for issuing landing order commands, and individual pilots were responsible for managing their local traffic situation by using their TSD's and by communicating directly with each other.

Study results showed that on the average, aircraft arrived at the Missed Approach Point at 64.5 second intervals. Both pilots and controllers felt that the centralized, ground-based management system was somewhat less safe and orderly than the distributed, pilot-spaced, management system. Pilots felt that the distributed system was more expeditious than the centralized system. The controllers reported the reverse opinion. Since the controllers were able to observe the overall flow of traffic on their display under both systems while the pilots were not, the controllers' judgement might be more relevant to system evaluation.

As expected, localizer and glide slope rms deviation during the last 3 nm of each approach (see Figure C-27), increased as the degree of turn increased. Although the number of missed approaches was low (14 of 350 approaches) the relative frequency was quite high on the Mercury approach. The poorer flight performance on that route could have been due to the steep turn required or the difficulty of reentering the traffic pattern following a previous missed approach. Pilot difficulty and safety ratings were inversely proportional to the amount of turning required. The relatively straight Viking and Gemini approaches were rated as very safe, whereas the Mercury approach was considered somewhat dangerous.

During the final debriefing, pilots expressed mixed reaction to the concept of closer spacing while controller's opinions were evenly divided between for and against. Pilots were much more positive regarding multiple curved descending approaches, particularly if spacing was increased, than controllers were. Managing aircraft merging from different directions was a difficult problem and the controllers indicated the need for additional information, such as estimated time of arrival and indicated air speed, to safely control traffic in this situation. All pilots and all but one controller considered the use of parallel runways, certified for simultaneous and independent operations under IFR conditions, to be a feasible procedure for

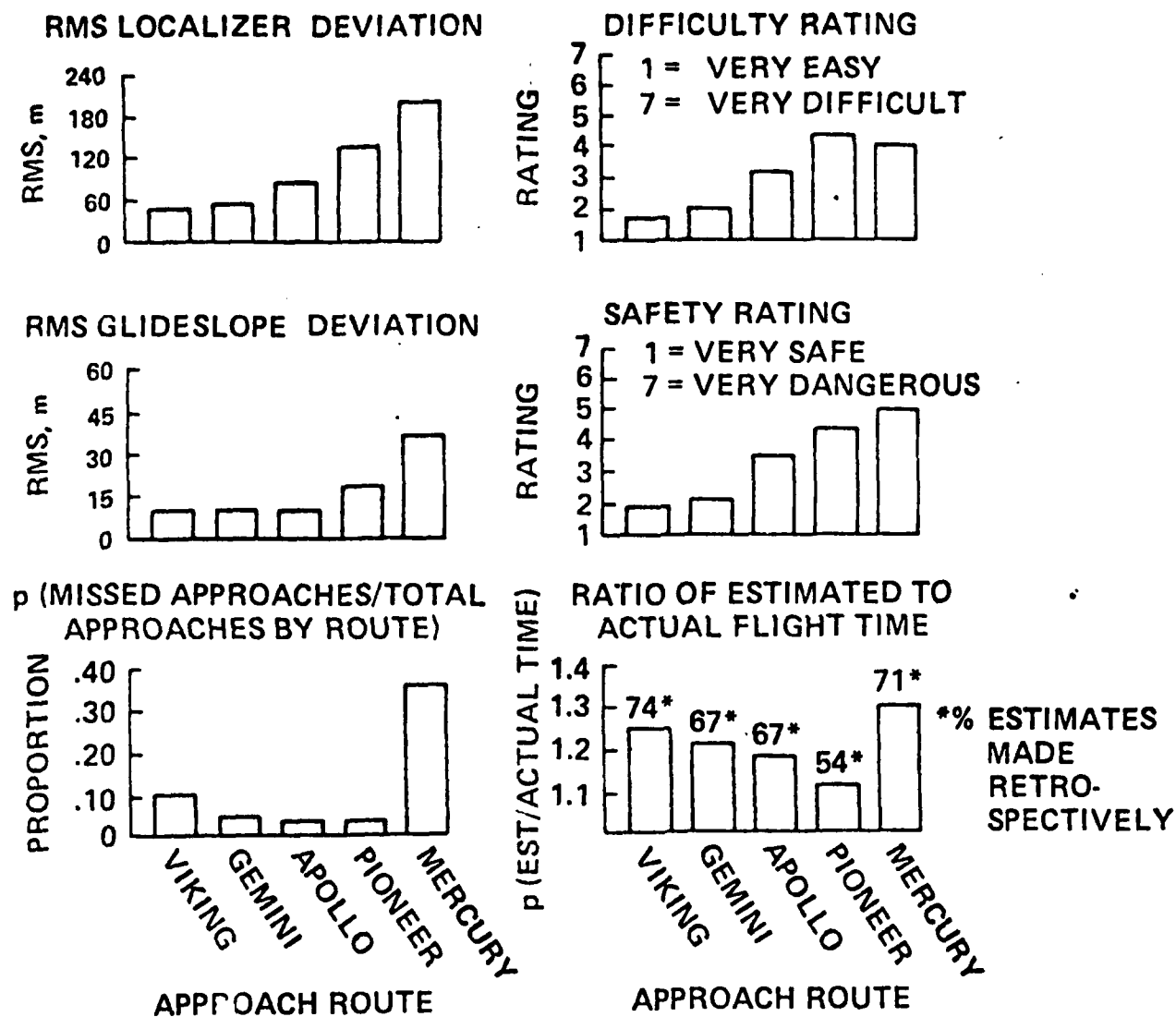


Figure C-27 Summary Of Results For Final 3 Miles Of Flight

increasing the rate of aircraft arrivals.

2.4.4 Other Studies

1) Reference 112 provides a detailed discussion on the airborne system requirements for transition from enroute navigation to approach guidance. The paper specifically addresses the RNAV to ILS and RNAV to MLS transitions in terms of the following issues: operational requirements and transitional considerations; computational requirements and system analysis; performance analysis and simulation results; and, display requirements. Many of the problems theorized in this report have been experienced in the USAF FPI program. Areas of this paper pertinent to the subject of this report are summarized below.

Due to the mixed airspace environment of navigational references which exists at the RNAV/MLS transition (i.e. VOR, DME, barometric altitude, MLS), problems are presented for both the airborne guidance and control system and the air traffic controller. Flight control is concerned with providing adequate performance in transitioning from one data source to another while ATC is concerned with controlling and monitoring flight paths and ensuring aircraft separation. Erratic maneuvers during transition or lack of transitional maneuvers may indicate possible system failure. Unnecessary false alarms would increase controller/pilot workload and communication channel usage.

A review of mixed airspace separation standards reveals the need for an increase in vertical but no increase in horizontal separations. Vertical navigation for departures must be referenced to barometric altitude since departing flight will have only partial MLS coverage at best. Due to typical departure routes which cross arrival paths and due to the errors between the MLS and barometric altitude references, an increase in vertical separation becomes a requirement. Analysis of a typical departure/arrival crossover 12 nm from the runway touchdown point (which presently requires 1500 feet separation with all aircraft using a barometric altitude reference) showed the need for 1600 to 1800 feet vertical separation from 10 to 30 nm from the MLS elevation site. No increase in horizontal separation standards are required in the mixed environment because the MLS system azimuth errors are

about 5 to 10 percent of those experienced with VOR (i.e. 0.2 versus 2.0 to 4.0 degrees, 2-sigma). Therefore, present standards already provide a conservative estimate of route width requirements in the MLS sector.

Guidance during the horizontal transition involves the elimination of large errors. Optimal filtering using VOR, DME, and MLS, whereby the MLS signal is slowly phased in as a function of distance to the azimuth transmitter, has been suggested as a method to reduce the effects of these errors on the maneuver transient. This was not required on the T-39 program, although variable time constants were employed in the simple complementary filter schemes to eliminate the effects of MLS noise at long ranges.

Possible maneuvers for the horizontal transition into MLS coverage are shown in Figure C-28. Track A,

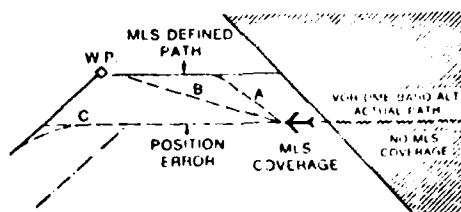


Figure C-28 Flight Path Definition Discontinuity

used exclusively on the USAF FPI Program and typical of present RNAV systems, results in an immediate corrective action to reduce the reference switchover error to zero. Errors in estimated position of 0.2 nm have been observed at VORTAC station changeover points. For MLS, however, the discontinuity may be as great as 0.5 nm. Based on a simulation using the lateral steering equations of the Collins ANS-70A Area Navigation System, the roll attitude and heading dynamic responses of an aircraft travelling at 180 knots ground speed to a 0.5 nm step input are shown

in Figure C-29. The responses indicate that the correction

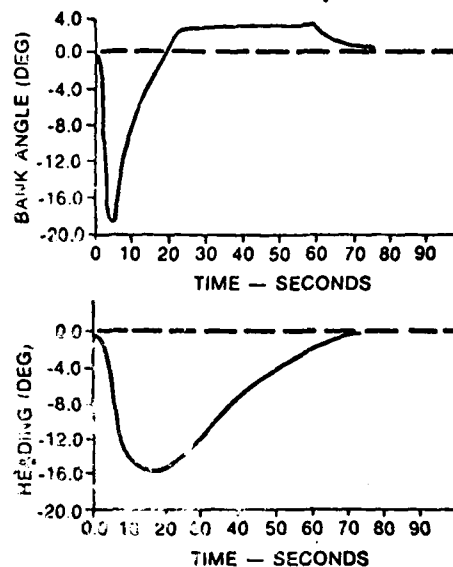


Figure C-29 ANS 70A Response To 0.5-NMI Step In Crosstrack At 180-Knot Ground Speed

is essentially complete after 60 seconds and a maximum bank angle of 18 degrees is achieved via roll rates of 5 degrees/second or less. From a pilot's standpoint each of these values are likely to be exceeded in routine terminal area maneuvering; moreover, if trajectories are flown such as those flown with the T-39, maneuvers approaching this will occur during circular transitions about straight-line segments later on in the approach. A key factor in pilot acceptance of such a maneuver is that adequate briefing must be provided so that an unexpected flight path change does not occur. ATC acceptance should not be a problem because the maximum heading change is only 15 degrees and is only momentary.

Two other methods to handle the transition are shown in tracks B and C. Both of these provide a gradual transition

to the MLS trajectory by sacrificing use of the accurate MLS data for possibly much longer periods of time.

Whichever transition technique is used, a fixed set of procedures must be established to reduce pilot and ATC workload and errors, and to permit automation of the maneuver. Due to the operational simplicity of the transition associated with track A and its immediate use of the MLS, it appears to be most attractive.

Guidance during the vertical transition poses several problems associated with pilot operational acceptance. Trajectory design must eliminate the problem associated with reducing large (500 feet) vertical transition errors above the desired path which may be descending at a 5 or 3 degree flight path angle. The profile geometry must provide the pilot with sufficient time to capture the vertical path without disconcerting flight path angle requirements. Special consideration must be given to pilot workload levels involved with simultaneous turn requirements. In such a maneuver, the pilot is required to change descent/ascent path, and lateral path while holding airspeed to safe levels. A second problem associated with the transition occurs as a result of errors where the aircraft is below the desired path. Since climbing to acquire the path is not normally operationally acceptable (for all but small errors, i.e., more than 100 feet, on T-39), logic or procedures are required to prevent a "fly up" to the path. The trajectory design, logic and procedures used on the T-39, and described in Section 2.4.1 appear to be an acceptable solution to these problems.

The paper also provided a cursory look at control/display requirements for MLS complex trajectory flight. The general opinion of the author was that, although further investigation was required, CRT map displays were not necessarily needed to execute terminal area paths where only minor impromptu modifications are used to achieve aircraft spacing and sequencing.

APPENDIX D

THREE-DIMENSIONAL IMAGE REPRESENTATION OF MLS TRAJECTORIES

One graphical entity presented to the pilot on the candidate 3-D Display is the dynamic 3-dimensional computer generated image which represents an MIS flight trajectory. The purpose of this 3-dimensional image is to provide the pilot with a precise, concise, scannable pictorial which allows him to ascertain his position as related to a desired real world MLS flight path.

D.1 Formats

The graphical structure of the image has been a topic of considerable investigation in recent years. The objectives of the investigations have been aimed at determining the optimal format of the image from a human engineering and computer real time standpoint.

The following criteria have been used to evaluate the displayed image:

1. A non-inverting 3-dimensional image (i.e., the image structure should not allow the pilot to perceive that the front of the displayed image becomes the back and vice versa).
2. The dynamic movement of the image on the display unit, in response to changes in aircraft position, should not be "distracting" to the pilot.
3. The image should retain its integrity for showing an unambiguous situation independent of the aircraft's position in 3D-space (i.e., the "image information content" should not degrade).
4. The image should be capable of indicating:
 - a. Cross track and vertical track errors.
 - b. Indications of the aircraft position above, below, left or right of his desired flight path.
 - c. Future MLS flight path changes in heading and altitude.
 - d. Aircraft roll angle.
 - e. A desired flight envelope about the desired flight path.and implicitly indicate:
 - a. Rate of climb or descent.

- b. Rate of change in aircraft heading.
- c. Rate of turn required to remain on defined flight path.
- d. Aircraft speed.

In accordance with item 2, to display a continuous dynamically moving image on the color display unit, the graphical structure must lend itself to airborne computer real time generation. This real time constraint imposes the criterion that the image be comprised of a minimum number of lines, since real time to generate the image is directly proportional to the number of lines when a hidden line algorithm is not used, and exponentially related when a hidden line algorithm is incorporated.

Figure D.1 shows three generically different image display formats (hereafter referred to as a tunnel, channel, and monorail representations) which were conceived as a result of the above criteria. (Note: The figures shown are examples of what the pilot would see on the cockpit display unit if he were exactly flying his desired MLS flight trajectory and no hidden line removal algorithm was incorporated.) The examples presented are pseudo perspective projections of an imaginary MLS "highway in the sky".

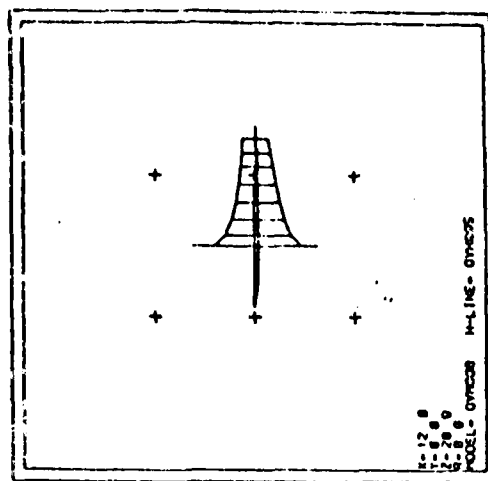
The figures which will be presented in this section are hard copies of images generated on a Tektronix 4081. The information shown in the lower left hand corner is a display of the X, Y, Z spatial coordinates (i.e., coordinates with respect to the fixed runway coordinate system) in normalized units (i.e., the values represent distances from the coordinate systems origin) of the aircraft or observation point. The R value shown is the roll angle of the aircraft/observation point in degrees.

The following subsections will discuss the characteristics of the three formats.

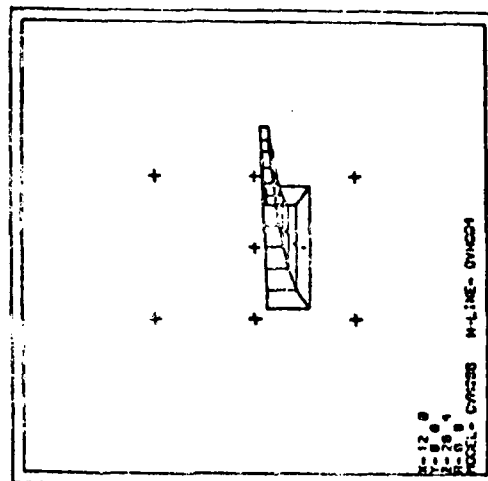
D.1.1 Tunnel Format

The tunnel format is comprised of a series of rectangular elements representing planes intersecting the desired MLS flight path at a constant interval along the path. The desired flight path trajectory is not explicitly represented by a line in this type of format, but implicitly represented by the center of each rectangular element.

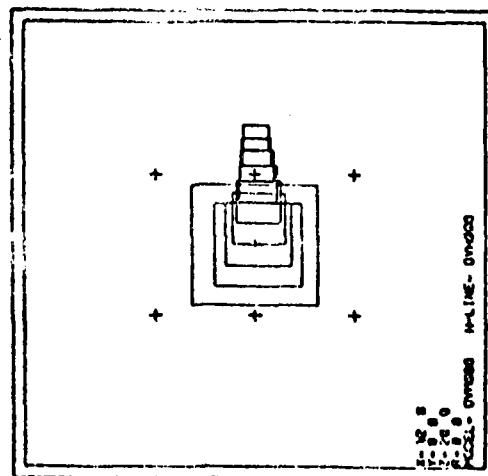
A major drawback to this approach is its ambiguity in explicitly indicating roll angle. For instance, at a roll angle of 45° , the direction of roll cannot be ascertained from the image presented to him since the rectangular elements are symmetrical. Using elongated elements aids in dispelling this ambiguity, but a similar ambiguity will still exist for certain angles.



(c) MONORAIL



(b) CHANNEL



(a) TUNNEL

Figure D-1 - Image Display Formats

D.1.2 Channel Format

Figure D-2 shows the basic graphical structure of the channel format and defines the elements in the structure (i.e., side posts, tar strips, etc.). In this format, the pilot's desired MLS trajectory is again not explicitly represented by a line on the display, but is implicitly located at the top, center of each channel segment. In essence, when the pilot is "on flight path" (as depicted in Figure D-2) the image displayed appears as a "highway in the sky" which extends out in front of the aircraft with the channel bed and center line positioned a channel height distance immediately below the desired flight path.

A major difficulty with the channel format is its tendency to invert or turn inside out in the viewers' eye. An example of this phenomena can be experienced by looking at Figure D-3(a). Employment of a hidden line algorithm and elimination of the center line when the channel is observed from below, improves the situation as demonstrated in Figure D-3(B). In addition to preventing image inversion, the use of hidden line removal in the channel approach, maintains the image integrity as shown in Figure D-4. The images represented in Figure D-4a, b, and c have degraded to a conglomeration of lines and the structure of the "highway in the sky" has been obliterated. Implementing hidden line clarifies the situation as shown in Figure D-4 d, e, and f. However, implementation of hidden line removal dramatically increases the computer real time to generate the image as well as reducing, in certain configurations, the amount of information about future flight path deviations in altitude and heading (refer to Figure D-4).

Since the channel format consists of four primitive graphical structures (side posts, tar strips, side rails, and channel front/back), each of these primitives can be displayed alone or in combination with other primitives. Figures D-5 and D-6 show some of the possible combinations. It should be noted that one of these channel format variations (Figure D-5(d) tar strips only) is currently being investigated by the Northrop Corporation for the Naval Air Development Center¹. On the surface, such an image format seems extremely feasible. However, investigation into the dynamics of a "tar strips only" format results in a major inadequacy as shown in Figure D-7. It is apparent that this display format has the characteristic of degrading, in certain situations, to an image which does not meet the criteria stated previously.

1. W. G. Mulley and J. F. Watler, Jr., "Feasibility Demonstration of the Earth-Referenced Maneuvering Flight Path Display", American Institute of Aeronautics and Astronautics Guidance and Control Conference, August 1977, Paper No. 77-114.

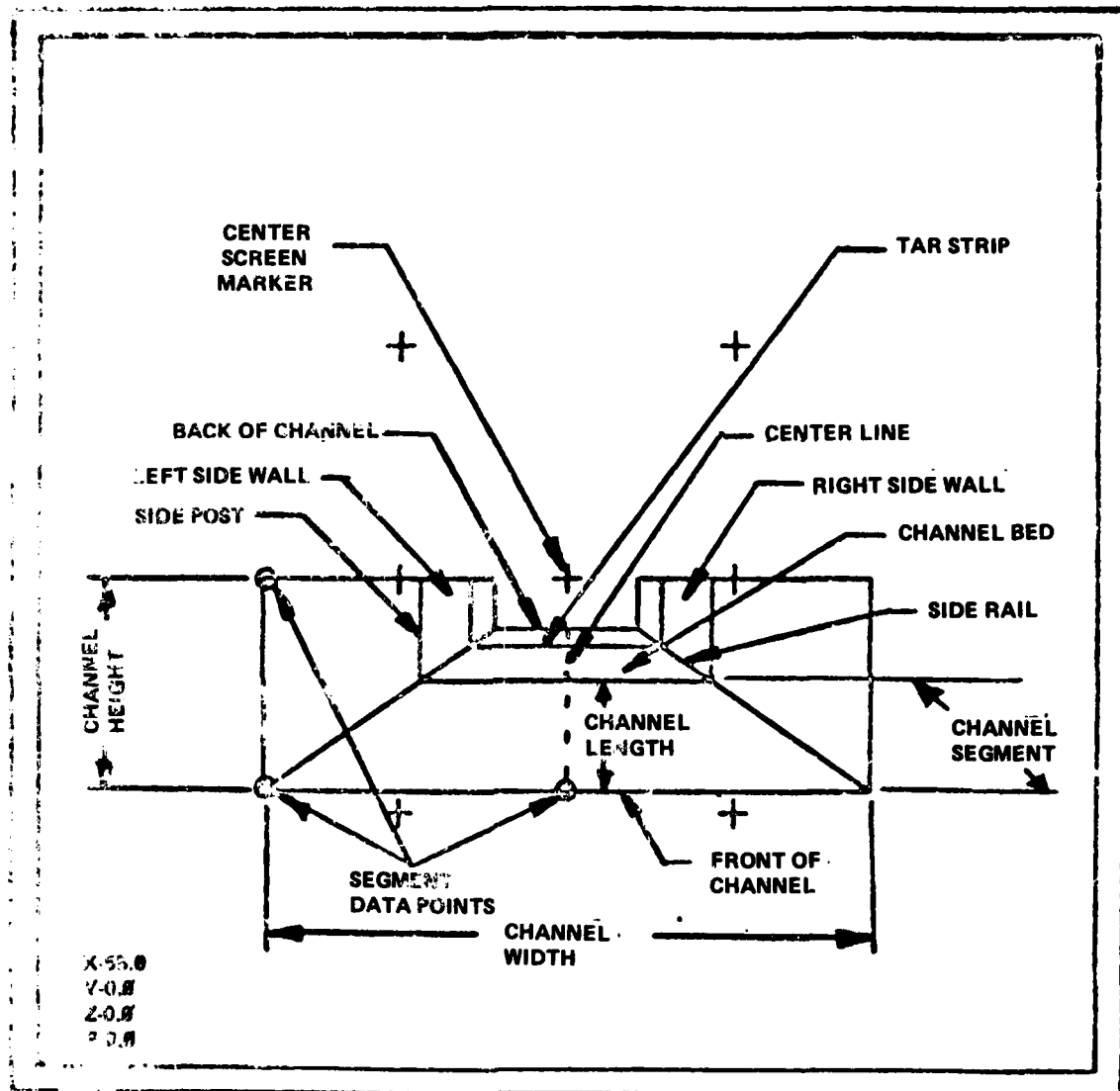
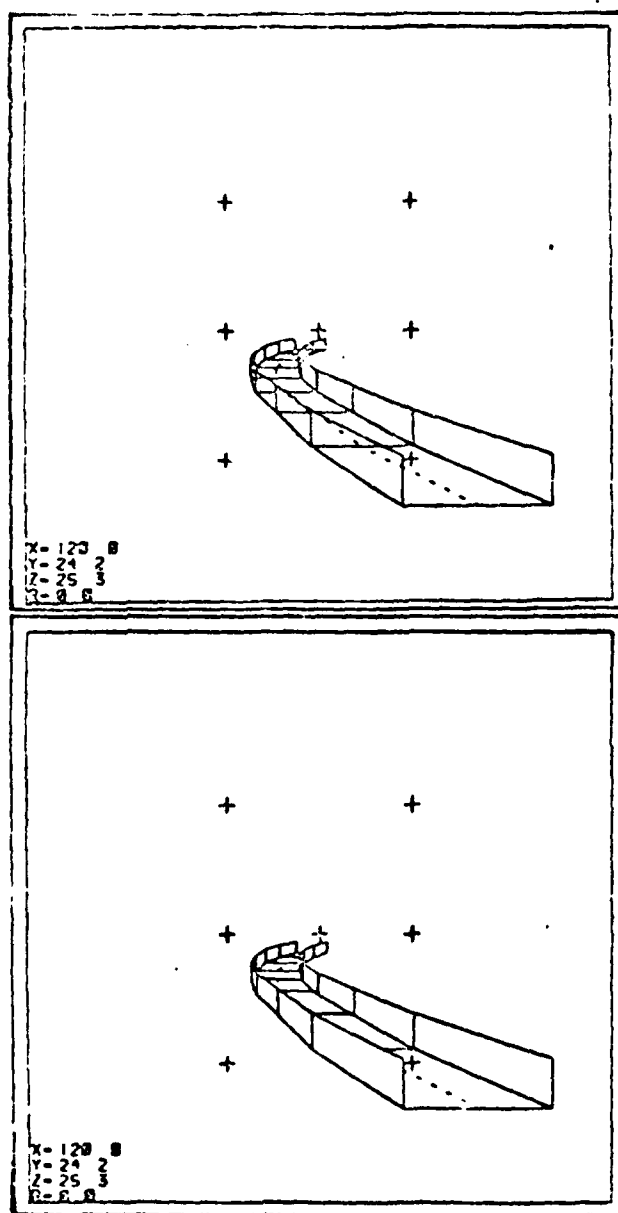


Figure D-2 - Channel Format Definitions



(a) NO HIDDEN LINE REMOVAL
(INVERTING IMAGE)

(b) HIDDEN LINES REMOVED
(NON-INVERTING IMAGE)

Figure D-3 Image Inversion Example

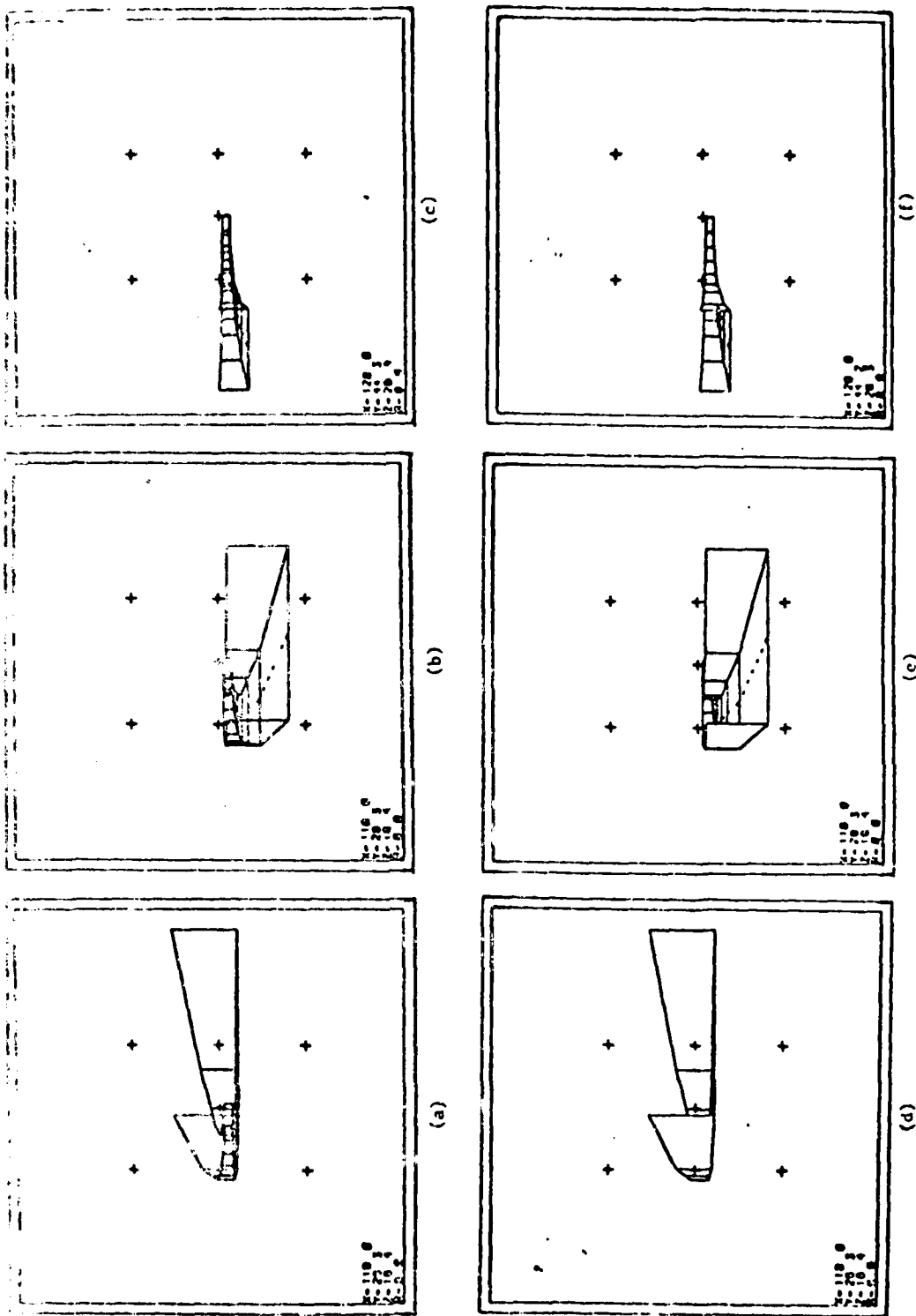
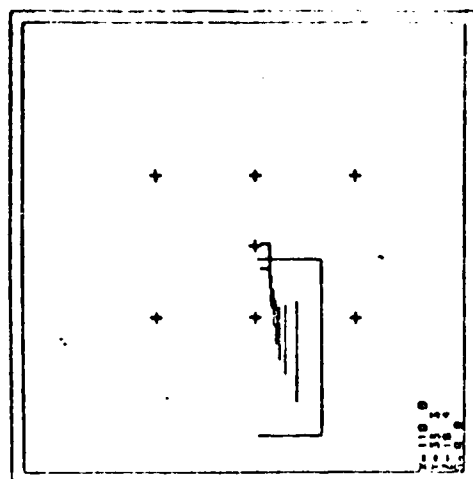
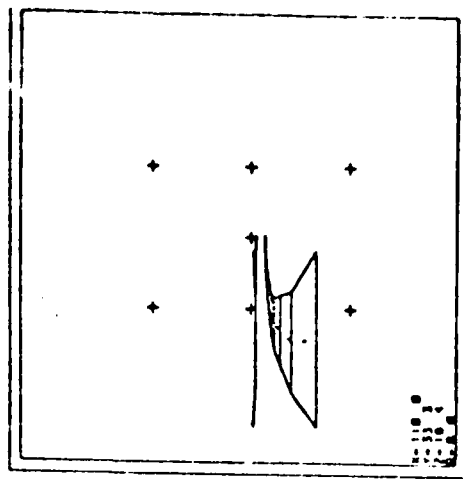


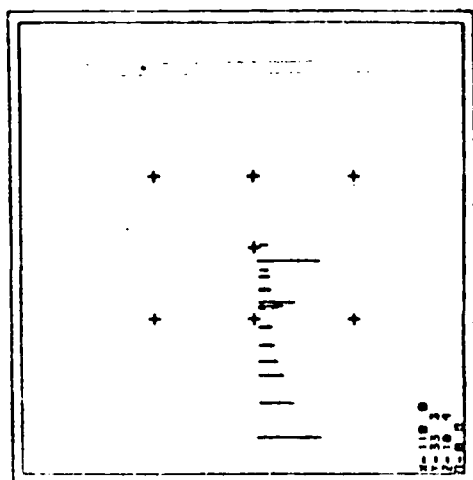
Figure D-4 Hidden Line Example



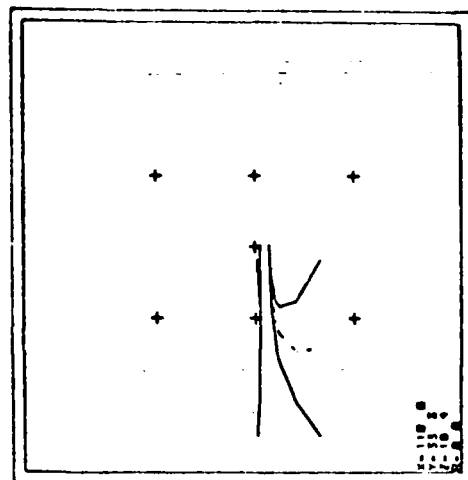
(c) TAR STRIPS AND CHANNEL FRONT/BACK



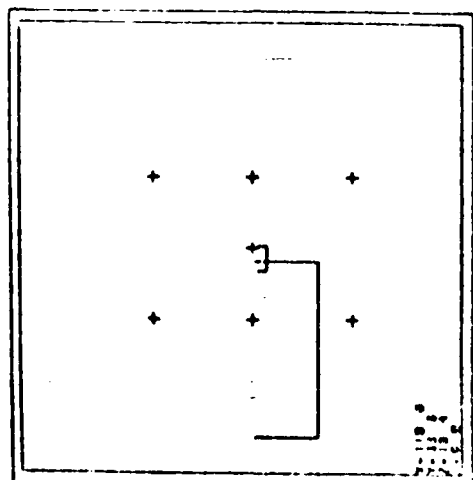
(f) TAR STRIPS AND RAILS



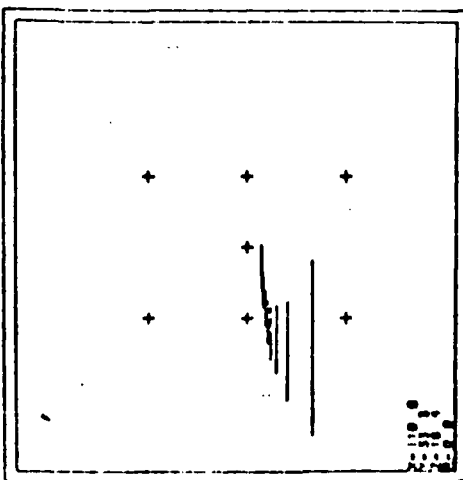
(b) CHANNEL SIDE POSTS ONLY



(e) RAILS ONLY

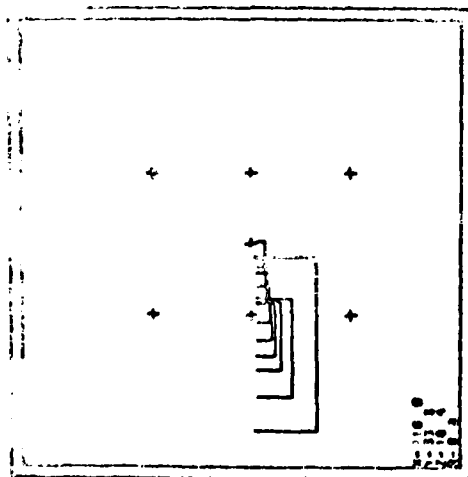


(d) CHANNEL FRONT/BACK ONLY

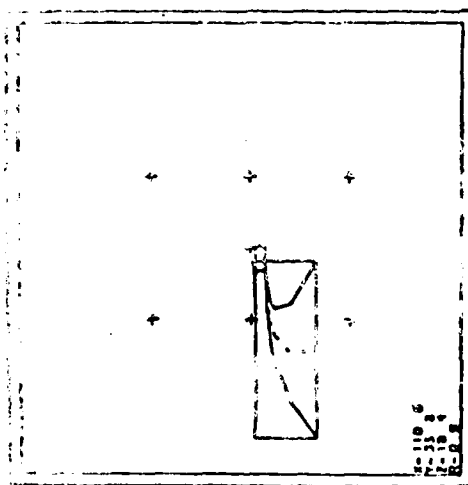


(g) TAR STRIPS ONLY

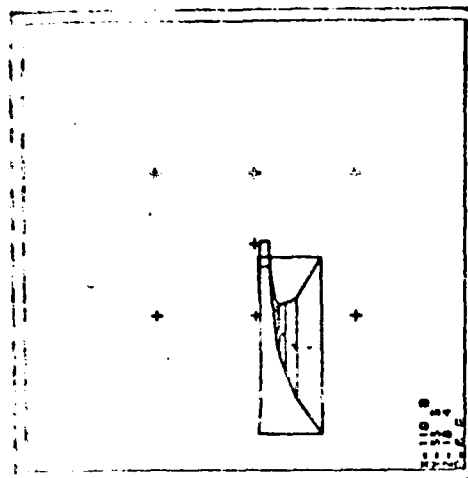
Figure D-5 Channel Format Variations



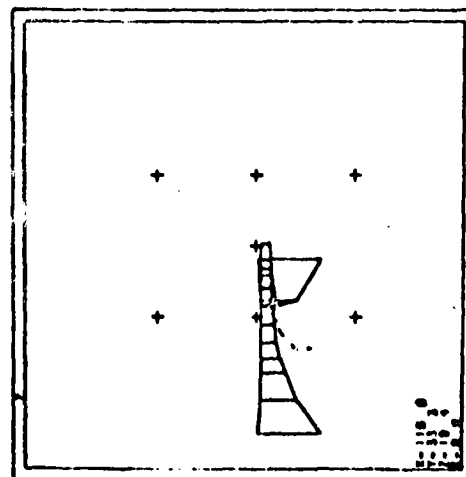
(a) TAR STRIPS AND SIDE POSTS



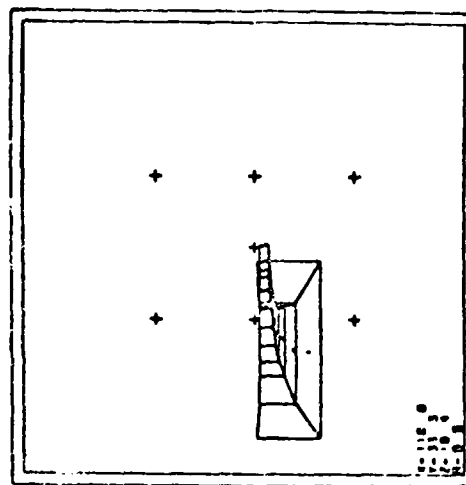
(b) RAILS AND CHANNEL FRONT/BACK



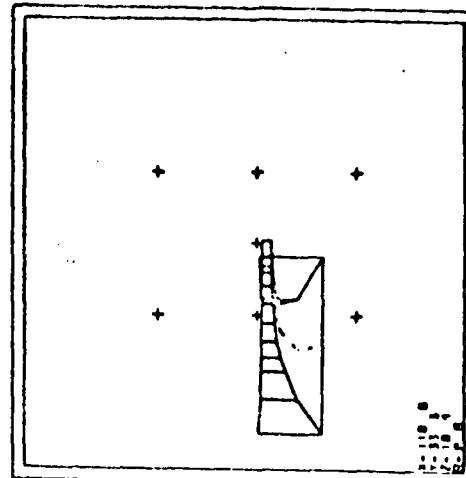
(c) TAR STRIPS, RAILS, AND CHANNEL FRONT/BACK



(d) SIDE POSTS AND RAILS



(e) SIDE POSTS, RAILS, TAR STRIPS, AND CHANNEL FRONT/BACK



(f) SIDE POSTS, RAILS, AND CHANNEL FRONT/BACK

Figure D-6 - Channel Format Variations

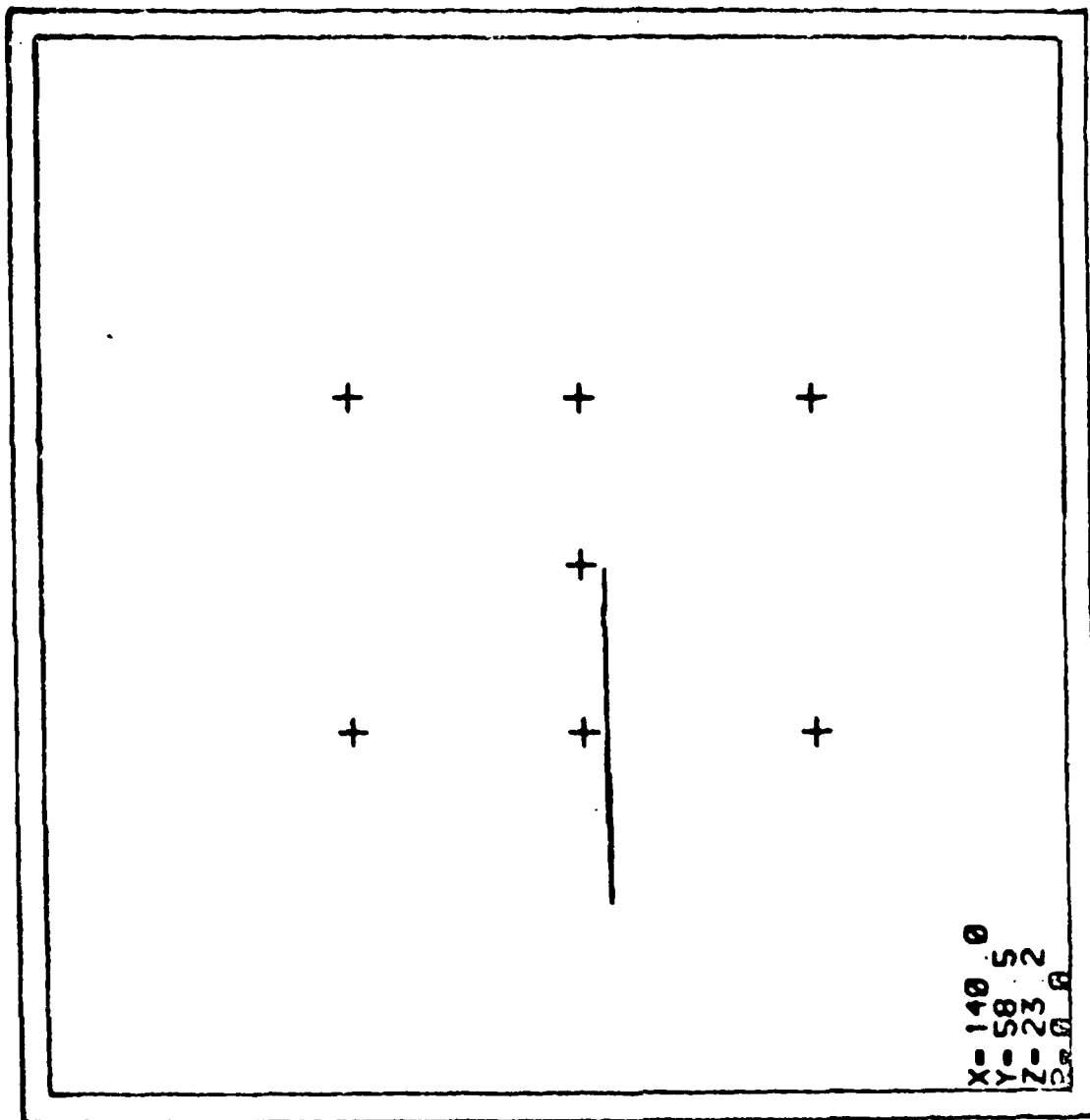


Figure D-7 Tar Strips Only

During the investigations into the different channel format variations, it is felt that a channel image comprised of side posts, side rails, and channel front/back primitives with implementation of a hidden line algorithm could be made to meet the human engineering and real time requirements. Figure D-8 is example display images which the pilot would see on the display unit in different flight situations.

The rate of change of cross track, vertical track, and roll angle can be implicitly derived by the pilot by monitoring the rate of horizontal, vertical and rotational changes of the image on the display. For example, if cross track error is increasing rapidly, then the image will move horizontally across the screen at a rate proportional to the aircraft's rate of change in the horizontal direction.

Progress along the flight path is implicitly determined from the movement of the side posts. The side posts increase in size and move as the aircraft proceeds along the flight path producing an illusion of flying down the channel.

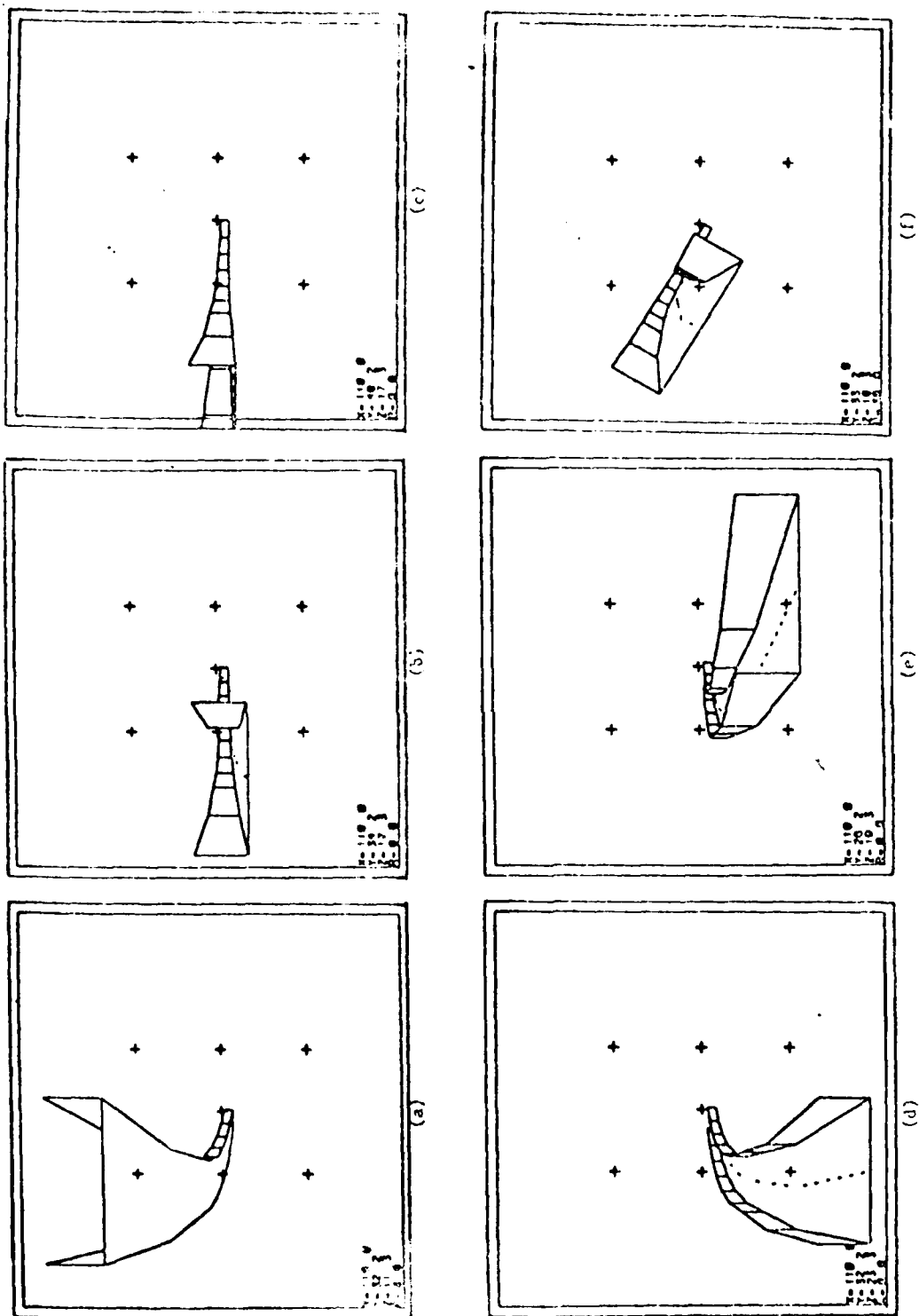
D.1.3 Monorail Format

In a monorail format, an MLS channel segment is represented by two perpendicular, intersecting planes. This format is similar to the "Bendix bull's-eye" presently used on conventional MLS. Unlike the previous two formats, the MLS flight path is explicitly represented by a line segment in the image. The line resulting from the intersection of the two planes is the MLS flight trajectory.

An interesting characteristic of this type of format is its relative stability with respect to image inversion, even without hidden line removal, the image does not easily invert in the viewer's eye (refer to Figure D.9). The pilot can easily ascertain the front and back of the image. However, without hidden line removal, the image is some-what busy.

The monorail format poses the same major drawback with respect to angle ambiguities as the tunnel format.

Figure D-10 shows example display images which the pilot would see on the display unit in different flight situations if the monorail format were implemented.



D-12

Figure D-8 - Channel Format Examples

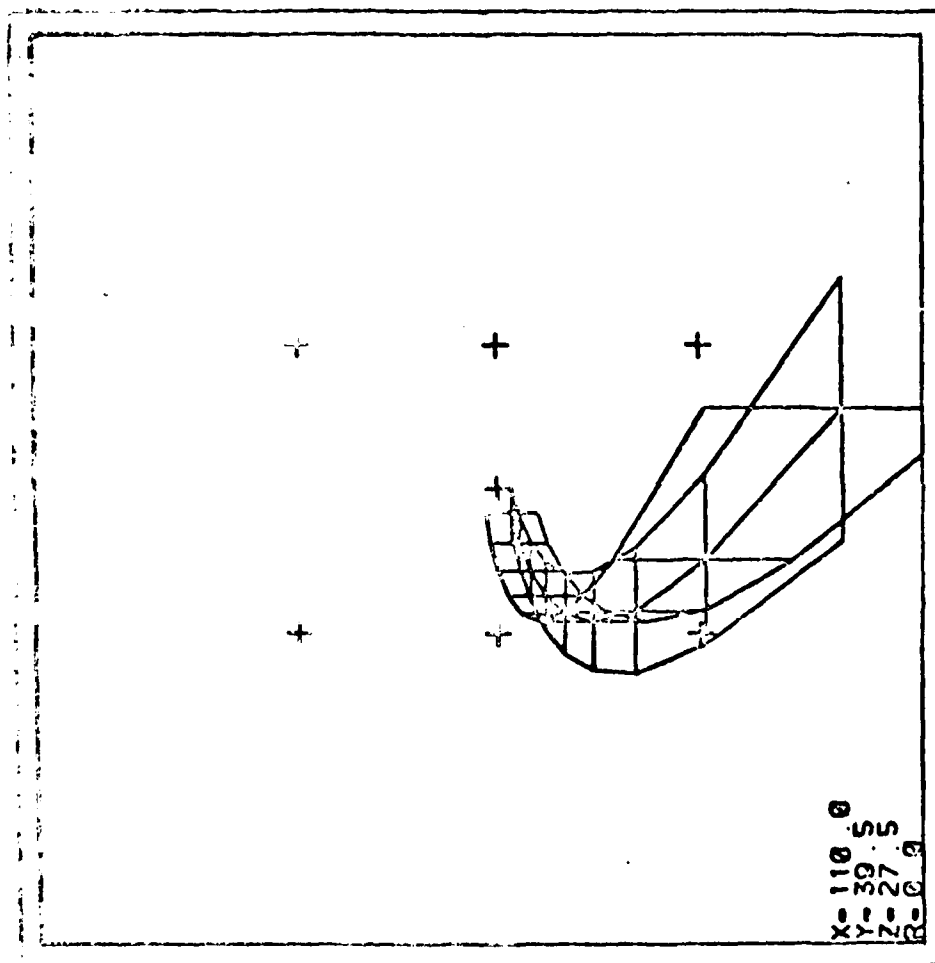


Figure D-9 - Monorail Format Examples

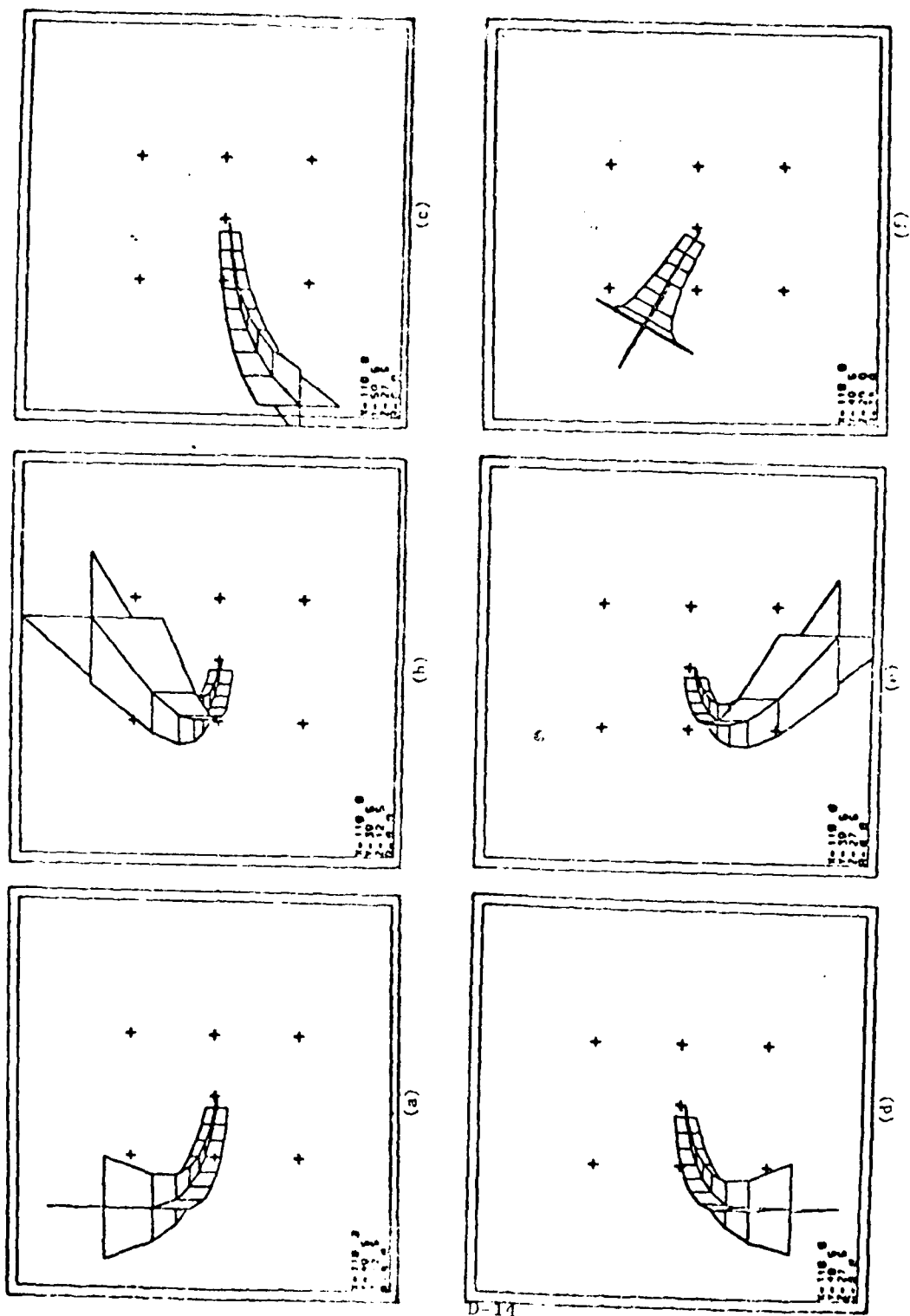


Figure D-10 - Monorail Format Examples

APPENDIX E

USAF T-39 MLS COMPLEX TRAJECTORY FLIGHT PILOT PROCEDURES

The following typical procedures are involved in flying an autopilot-coupled MLS complex trajectory with the present USAF T-39 control and display configuration. Comments are shown in parentheses following the specific task. Reference should be made to the T-39 panels and displays shown in Section 2.4.1.

Initial Set-Up Prior to Entering MLS Data Coverage

1. Turn on CDU and set barometric pressure and outside air temperature readouts via CDU and MEM pushbuttons and encoder knob. (It would be better if this were done automatically by monitoring the altimeter setting and measuring OAT).
2. Monitor and contact enroute center and approach control frequencies as required. Transmit desired Profile # to approach control and obtain clearance. (Normally ATC will issue an approach path based on current traffic).
3. Select TACAN channel and set up course to intercept first leg of MLS approach on co-pilot's HSI
4. Check and set Nav Select Panel (NSP) switches as follows:
 - a. Pilot's DEV switch to CDU - SET
 - b. Pilot's BRG switch to MLS - SET
 - c. Copilot's DEV switch to TAC - SET
 - d. Copilot's BRG switch to TAC - SET
 - e. CDU/DME switch to WPT - Check
 - f. MLS/TKR switch to TKR - Check
 - g. VERT switch to WPT - Check
5. Check and set MLS Control Panel switches as follows:
 - a. MLS CHAN selector to desired channel - set three thumbwheel switches.
 - b. AZ selector to 000 - check
 - c. GS selector to 3.0 - check
 - d. MLS/OFF/VOR TAC switch to MLS - set

6. Select AZ readout on MLS Auxiliary Data Panel.
7. Set VOR frequency paired with airport's MLS DME frequency on pilot's side of VHF NAV control head. Check that pilot's DME light on control head is illuminated. If not, depress DME transfer pushbutton once. (In the final MLS configuration, the MLS DME frequency will be paired with the MLS channel thereby eliminating this step.)
8. Check and set autopilot/flight director Mode Select Panel switches as follows:
 - a. Flight director engaged - check for command bars in view on ADI.
 - b. AUTOPILOT switch on - check
 - c. ROLL and PITCH axes switches in CMD - check
 - d. CWS switch in ON position - check
9. Maneuver aircraft via roll CWS to fly TACAN radial which will intercept MLS. (The coupled heading select mode could also have been used).
10. Maneuver aircraft via pitch CWS to obtain desired level flight altitude, then engage altitude hold by depressing ALT HOLD pushbutton on Mode Select Panel.
11. Depress DIG pushbutton on Nav Select Panel to engage digital autopilot. (This could have been on before.)
12. Insert approach profile into computer via CDU*, and check data entry vs. the approach plate, as follows:
 - a. Insert desired profile number on "altitude page"

*CDU data entry involves: selecting the desired "page" of information by actuation of two pushbuttons; selecting the desired data parameter mnemonics to be changed by repeated actuation of the LINE pushbutton until that mnemonic is flashing; rotating the encoder knob until the desired value appears next to the identifier; and, depressing the MEM (memorize) pushbutton.

12. Select "waypoint sequence page" and check the sequence of waypoint numbers defining the desired trajectory.
- c. Select "waypoint display page" for each waypoint (typically 3 or 4 waypoints not including GPIP) and check waypoint bearing (azimuth) and range (DME).
- d. Select "lateral page" for each waypoint and check inbound and outbound tracks (courses) and radius on turn. The inbound track of the initial MLS waypoint may require change.
- e. Select "vertical page" for each waypoint and check desired altitude and path angles for waypoint. Altitudes, in some cases, will require change. Incorrect altitudes will result in erroneous desired, and next, path angle and indications.
13. Lower speed brake.
14. Adjust power settings for approach speed and control power as required.
15. Lower landing gear and flaps.
16. Check fuel quantity, fuel heater and hydraulic pressure.
17. Turn on landing light, seat belt and no smoking signs.
18. Set decision height bug on radar altimeter indicator.

Monitor the following to Detect Entry into MLS Data Coverage

1. FACAV lateral deviation and DME data vs. approach plane indication of MLS entry point data
2. FACAV azimuth, elevation and DME data by in-view indications on MLS Auxiliary Data Panel, Vertical Angle Indicator and MLS DME Indicators, respectively. (Too many different displays.)

After Recognition of Valid MLS Data

1. Engage MLS Mode on CDU by the following operations:
 - a. Depress LAT and MEM pushbuttons.

- b. After 3 seconds observe: LAT green light on CDU; slewing of Pilot's HSI course to that of initial MLS approach segment; and, the "to" waypoint number on the CDU.
 - c. Depress VERT and MEM pushbuttons
 - d. After 1 second observe VERT green light on CDU.
(Could be done using one pushbutton - MLS on.)
 - * 2. Select autopilot/flight director MLS lateral and vertical navigation modes via Mode Select Panel.
 - a. Depress LAT NAV pushbutton
 - b. Depress VERT NAV pushbutton
(Could be done using one pushbutton - MLS.)
 - * 3. Observe pilot's or copilot's mode progress displays for autopilot/flight director MLS arm and/or engage status.
 - 4. If modes are armed (annunciated by amber AZ and EL indications in arm window) observe the HSI and ADI deviation and situation indications described below:
 - a. Aircraft below desired glide path and intercepting.
 - b. Aircraft at an intercept angle to the desired course.
 - c. If these situations are incorrect, they should be attained via CWS.
- *(By modifying the MLS computer logic these steps can be accomplished prior to entering MLS coverage. This would greatly reduce workload levels at the transition point. It would also eliminate the need to closely monitor for the point where MLS data first became valid.)
- 5. When the lateral and vertical navigation modes' capture logic is satisfied, the individual mode will be automatically engaged and annunciated by a green AZ and/or EL in the engage window of the mode progress display. The aircraft will be maneuvered by the autopilot in a smooth manner to capture the transition segment within MLS coverage.

6. Path tracking and approach progress is monitored using the following presentations on the following instruments:
- a. ADI-GS pointer for vertical deviation about the command descent path, pitch and roll attitude, flight director command bars and flight path angle.
 - b. HSI - course deviation for lateral deviation about the desired track (i.e., course), desired track angle for the current lateral path segment, DME to waypoint, bearing to waypoint on the bearing pointer and aircraft heading.
 - c. MLS DME Indicator - DME to MLS DME site at far end of runway.
 - d. MLS Auxiliary Data Panel - Azimuth angle referenced to 0° along the runway centerline.
 - e. Azimuth Angle Indicator (AAI) - nonlinear analog display of azimuth angle.
 - f. Vertical Angle Indicator (VAI) - non-linear analog display of elevation angle.
 - g. CDU "data page 1" - digital readouts of lateral deviation with a resolution of 0.01 NM, vertical deviation in feet, range-to-waypoint with a resolution of 0.1 NM and estimated-time-to-go to the next waypoint with a resolution of 0.1 minutes
- (Again, too many displays.)
7. Circular arc lateral transitions are monitored by observing:
- a. DME to waypoint
 - b. Flashing green LAT and ALRT lights on CDU for 15 seconds prior to the turn.
 - c. Automatic slewing of the course pointer to the next desired track.
 - d. Course on which rollout occurs.
 - e. Magnitude of the bank angle during the turn.
8. Vertical position and transitions are monitored using DME to the DME site, barometric altitude and rate of descent indications.

9. After final approach track (i.e., runway heading and final descent angle) is attained, the lateral and vertical deviation indications on the HSI and ADI automatically switchover from MLS navigation computer data to MLS receiver raw data. This is annunciated by either an amber CATII or ALN/FLR (depending on whether autoland was selected) readout in the arm window of the mode progress display.
10. To determine the time-to-go to touchdown, as is often requested by approach control, the CDU/DME switch on the Nav Select Panel is moved to the ATK position and the ETG is read on "data page 1" of the CDU.

Warning and Failure Indications

1. An MLS receiver failure, or loss of valid MLS data due to antenna masking, is annunciated by a red D/R light on the CDU. No flags come in view on the HSI or ADI; however, the data which goes invalid or fails is biased out of view or flagged on its specific indicator as described below:
 - a. Loss of Azimuth data is indicated by displacing the AAI bar fully to the left and by displaying all dashes on the MLS Auxiliary Data Panel AZ readout.
 - b. Loss of elevation data hides the VAI pointer.
 - c. Loss of DME data is indicated by displaying all dashes on the MLS DME Indicator.